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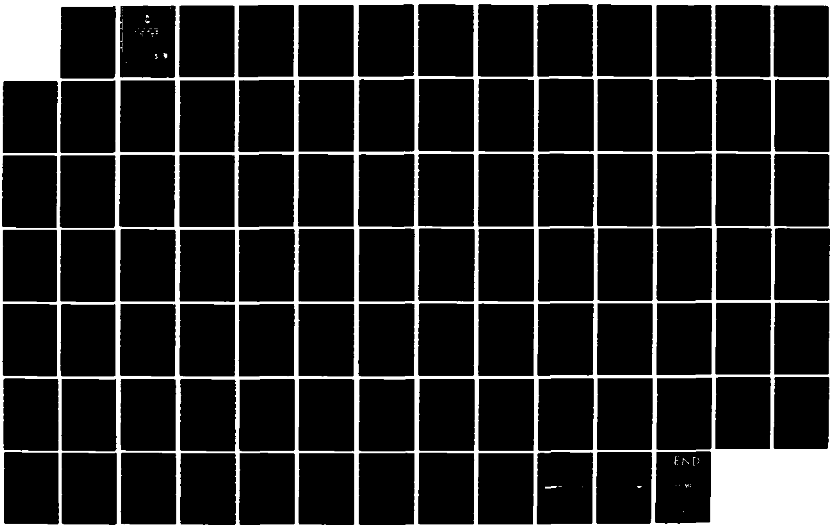

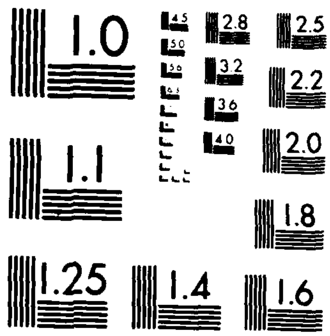

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

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SIMULATION OF SPACE BASED RADAR SURVEILLANCE SYSTEMS II: SOFTWARE TO PERFORM TIME OF REVISIT STUDIES

by

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ABSTRACT

A computer simulation of the coverage of satellite borne radars with mechanical and/or electronic scanning mode has been implemented in APL language. The number of revisits and the revisit time are calculated for a set of points of reference. The programs are producing either paper print-out or graphic displays on a Tektronic screen. This simulation is a component of a software package designed to study space based radar surveillance systems.

RÉSUMÉ

On présente une simulation par ordinateur en language APL de la couverture de radars montés sur satellites à balayage électronique ét/ou mécanique. Les programes produisent une sortie imprimée ou afflichent les données sur écran Tektronix. On calcule l'intervalle entre les visites et le nombre de revisites pour un ensemble de points de référence. Cette simulation fait partie d'un ensemble de logiciels destinés à l'analyse de systèmes de surveillance par radars montés sur satellites.

ACKNOWLEDGEMENT

The author would like to thank Mr. R.H. Martin and Dr. A.W. Bridgewater both from the Communications Research Center, for many helpful discussions.

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Introduction

TSATCO and SATCO are two complementary workspaces whose function is to calculate, for a set of reference points, the number of revisit and the revisit time associated to a particular system of satellites described by the variable SYSAT. TSATCO generates a graphic display on a Tektronix screen and SATCO generates a print-out of a few variables of interest. TSATCO is used to check the results obtained from SATCO and to set-up the time interval that is appropriate to a particular situation. The components of the system of satellites are defined by the user through the definition of the variable SYSAT.

Function of the Workspace TSATCO and SATCO:

- Calculates the position of the satellites,
- Calculates the coverage area of the satellites,
- Checks if one or more of the check points are within the coverage areas,
- Computes the revisit times and the number of revisits, for every reference point,
- TSATCO displays the satellite position and the coverage area if the coverage area includes one of the reference points,
- SATCO prints a few parameters of interest,
- SATCO, at the end of one execution of CONTROL, is saved in a workspace named DATACO. The values of the revisit time and of the number of revisits are thus saved and it is possible to further process them, before another execution of CONTROL, with the program COURBE and HISTO.

Mode of Operation

The calculations are made at a regular time interval from a time origin, both are set by the operator. The calculations are separated in pockets of a certain number of time points such that the parallel processing capabilities of APL are used to the maximum without exceeding the available memory of the workspace. The number of time points processed in parallel is given by the variable NLIM that the user can change at will on line 22 and 21 of TSATCO and SATCO respectively.

Reference points:

The reference points are located at longitude 0 and latitude 90°, 80°, 70°, 60°, 50°, 40°, 30°, 20°, 10° and 0° in geographical coordinates (EGR system).

Example of Results

We included an example of the output of TSATCO (see Fig. 1) and SATCO (see Table 1) with

- starting time of the simulation: 0
- time increment: 5
- duration of the simulation: 150

We had a system of two satellites on the same circular polar orbit at an altitude of 300 km but spaced in time by 15 minutes. One of the satellites was of the mechanically scanning type and the other was of the electronically scanning type. The SYSAT array was:

300	300	-.5	.866	0	0	0	1	0	0	3	0
300	300	-.5	.866	0	0	0	1	15	1	3	90

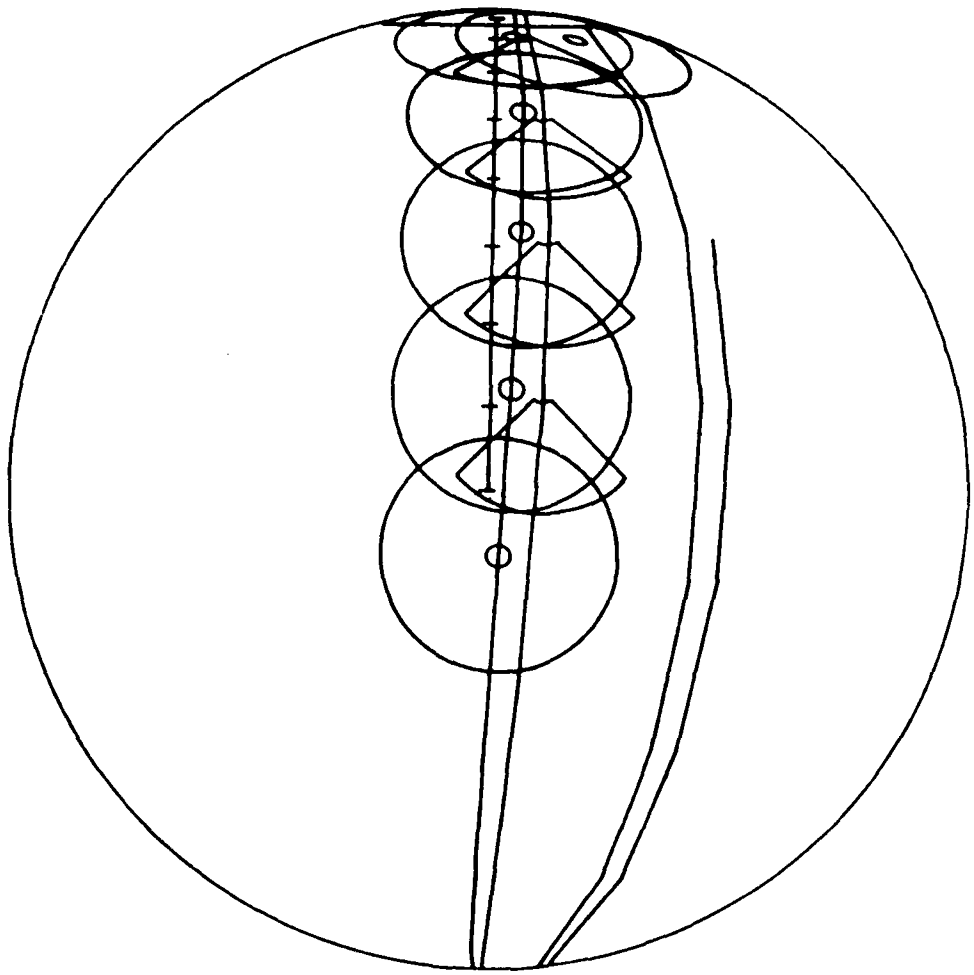


Figure 1: Typical output of TSATCO

```
)WSID
IS              SATCO
      CONTROL
STARTING TIME OF THE SIMULATION=
]:
      0
TIME INCREMENT=
]:
      5
DURATION OF SIMULATION=
]:
      150
POSITION OF THE OBSERVATION POINT
ALTITUDE ABOVE EARTH SURFACE=0
LONGITUDE=0
LATITUDE=0

NTP=2  IS=1   T=0
DFO=1  1  0  0  0  0  0  0  0  0
TREVS=
   0   0 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
TREV=0  0  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26
NREV=1  1  0  0  0  0  0  0  0  0

NTP=2  IS=1   T=5
DFO=0  1  1  0  0  0  0  0  0  0
TREVS=
   0   0   5 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
TREV=0  0  5  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26
NREV=1  1  1  0  0  0  0  0  0  0

NTP=2  IS=2   T=75
DFO=1  1  0  0  0  0  0  0  0  0
TREVS=
   0   0   5 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
  75  75 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
TREV=75  75  5  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26
NREV=2  2  1  0  0  0  0  0  0  0

NTP=1  IS=2   T=80
DFO=0  0  0  1  0  0  0  0  0  0
TREVS=
   0   0   5 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
  75  75 ¯26  80 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
TREV=75  75  5  80  ¯26  ¯26  ¯26  ¯26  ¯26  ¯26
NREV=2  2  1  1  0  0  0  0  0  0
```

TABLE 1: TYPICAL OUTPUT OF SATCO

```
NTP=1   IS=2   T=85
DFO=0  0  0  0  0  1  0  0  0  0
TREVS=
  0   0   5 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 75  75 ¯26  80 ¯26  85 ¯26 ¯26 ¯26 ¯26
TREV=75  75  5  80  ¯26  85  ¯26  ¯26  ¯26  ¯26
NREV=2  2  1  1  0  1  0  0  0  0

NTP=2   IS=1   T=90
DFO=1  1  0  0  0  0  0  0  0  0
TREVS=
 90  90   5 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 75  75 ¯26  80 ¯26  85 ¯26 ¯26 ¯26 ¯26
TREV=90  90  5  80  ¯26  85  ¯26  ¯26  ¯26  ¯26
NREV=3  3  1  1  0  1  0  0  0  0

NTP=1   IS=2   T=90
DFO=0  0  0  0  0  0  0  1  0  0
TREVS=
 90  90   5 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 75  75 ¯26  80 ¯26  85 ¯26  90 ¯26 ¯26
TREV=90  90  5  80  ¯26  85  ¯26  90  ¯26  ¯26
NREV=3  3  1  1  0  1  0  1  0  0

NTP=3   IS=1   T=95
DFO=0  1  1  1  0  0  0  0  0  0
TREVS=
 90  90  95  95 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 75  75 ¯26  80 ¯26  85 ¯26  90 ¯26 ¯26
TREV=90  90  95  95  ¯26  85  ¯26  90  ¯26  ¯26
NREV=3  3  2  2  0  1  0  1  0  0

NTP=1   IS=2   T=95
DFO=0  0  0  0  0  0  0  0  0  1
TREVS=
 90  90  95  95 ¯26 ¯26 ¯26 ¯26 ¯26 ¯26
 75  75 ¯26  80 ¯26  85 ¯26  90 ¯26  95
TREV=90  90  95  95  ¯26  85  ¯26  90  ¯26  95
NREV=3  3  2  2  0  1  0  1  0  1

NTP=3   IS=1   T=100
DFO=0  0  0  1  1  1  0  0  0  0
TREVS=
  90   90   95   95  100  100  ¯26  ¯26  ¯26  ¯26
  75   75  ¯26   80  ¯26   85  ¯26   90  ¯26   95
TREV=90  90  95  95  100  100  ¯26  90  ¯26  95
NREV=3  3  2  2  1  2  0  1  0  1
```

TABLE 1: TYPICAL OUTPUT OF SATCO

```
VTP=3   IS=1    T=105
DFO=0  0  0  0  0  1  1  1  0  0
TREVS=
   90    90    95    95   100   100   105   105   ¯26   ¯26
   75    75   ¯26    80   ¯26    85   ¯26    90   ¯26    95
TREV=90   90   95   95   100   100   105   105   ¯26   95
NREV=3   3   2   2   1   2   1   2   0   1

VTP=3   IS=1    T=110
DFO=0  0  0  0  0  0  0  1  1  1
TREVS=
   90    90    95    95   100   100   105   105   110   110
   75    75   ¯26    80   ¯26    85   ¯26    90   ¯26    95
TREV=90   90   95   95   100   100   105   105   110   110
NREV=3   3   2   2   1   2   1   2   1   2

VTP=1   IS=1    T=115
DFO=0  0  0  0  0  0  0  0  0  1
TREVS=
   90    90    95    95   100   100   105   105   110   110
   75    75   ¯26    80   ¯26    85   ¯26    90   ¯26    95
TREV=90   90   95   95   100   100   105   105   110   110
NREV=3   3   2   2   1   2   1   2   1   2
REV1=26   75   15
REV2=26   75   15
REV3=31   90
REV4=106   15
REV5=126
REV6=111   15
REV7=131
REV8=116   15
REV9=136
REV0=121   15
SYSAT=
   300        300          ¯0.5         0.866        0
             0           0           1           0           0
             3           0
   300        300          ¯0.5         0.866        0
             0           0           1          15           1
             3          90
WAS           SATCO
 DATACO       SAVED  11:39 NOV 26,'81
```

TABLE 1: TYPICAL OUTPUT OF SATCO

List of the systems of coordinates used in the programs

Name	Center	Type	Rotation[a] with the Earth	Orientation of the axis
ERF	Earth	rectangular	No	Z-North Pole; X at 0° lat. and 0° long. at t=0; see Fig. 2.
ESF	Earth	spherical Z[b]	No	from ERF; see Fig. 2.
ERR	Earth	rectangular	Yes	Z-North Pole; X at 0° lat. and 0° long; at anytime
ESR	Earth	spherical Z[b]	Yes	From ERR, see Fig. 2.
ERE	Earth	rectangular	No	Z-perpendicular to the orbital plane; X toward perigee; see Fig. 3
ESE	Earth	spherical Z[b]	No	From ERE; see Fig. 2 and 3.
EGR	Earth	geographic	Yes	Altitude: from the center of the Earth; longitude, latitude; see Fig. 4
SRT	satellite	rectangular	-	topocentric (4); (see Fig. 3).
SST	satellite	spherical Z[b]	-	From SRT
SXT	satellite	spherical X[c]	-	From SRT (see Fig. 5)
SRE	satellite	rectangular	-	Z-perpendicular to the orbital plane; X in the direction of the movement (see Fig. 5).
SXE	satellite	spherical X[c]	-	From SRE (see Fig. 5).
ORR	point of observation	rectangular	Yes	Topocentric (see Fig. 6).

(a) Yes means that the system of coordinates rotates with the Earth. No means that the system of coordinates does not rotate. It is just tied to the center of the Earth and assumed to keep a constant orientation relative to the stars. The movement of the Earth around the Sun are thus neglected.

(b) Spherical coordinates with the angle ϕ measured from the Z axis (see Fig. 2).

(c) Spherical coordinates with the angle ϕ measured from the X axis (see Fig. 5).

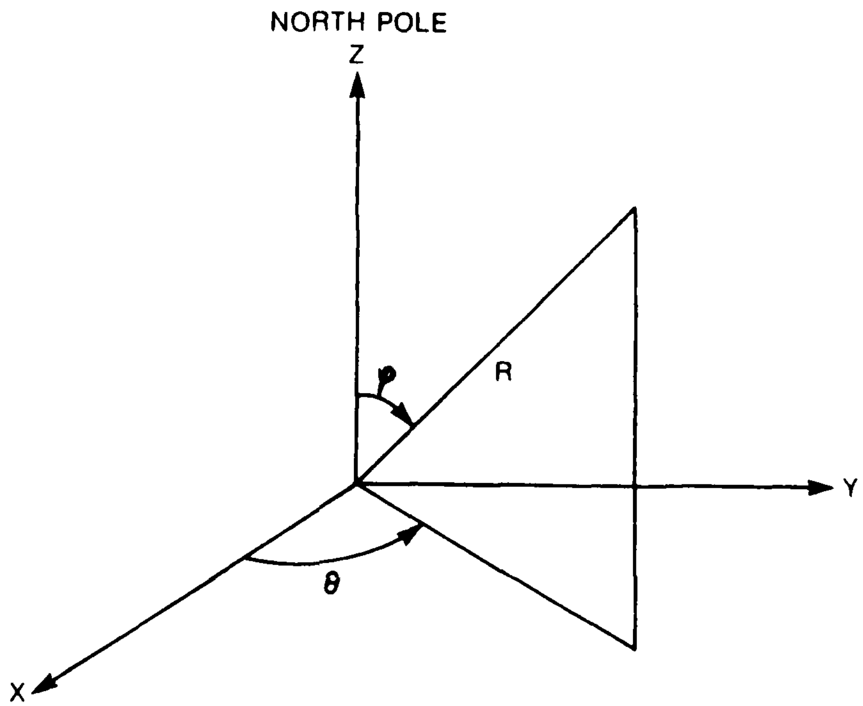


Figure 2: Relationship between rectangular and spherical coordinates and position of the fixed coordinates system

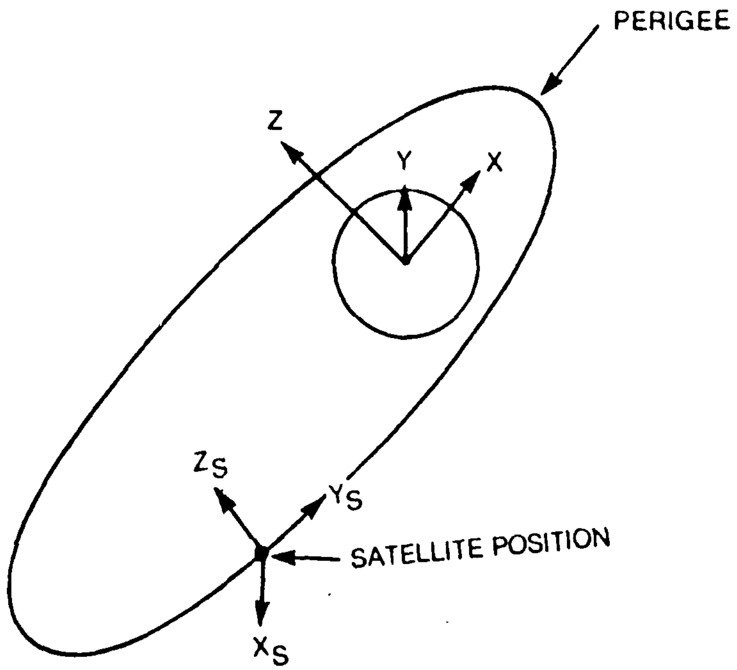


Figure 3: System of coordinates used to describe the motion of the satellites

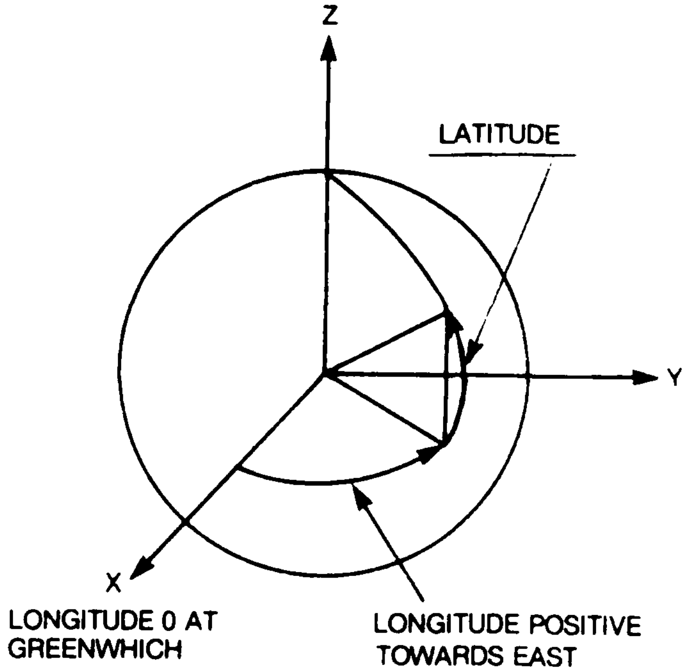


Figure 4: Geographic coordinates

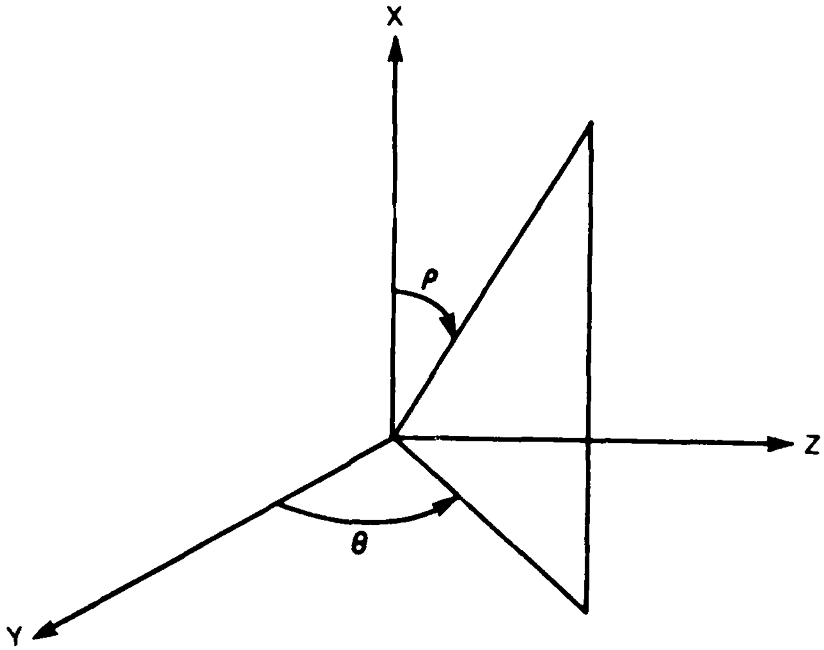


Figure 5: Spherical system of coordinates with the angle ϕ measured from the X axis

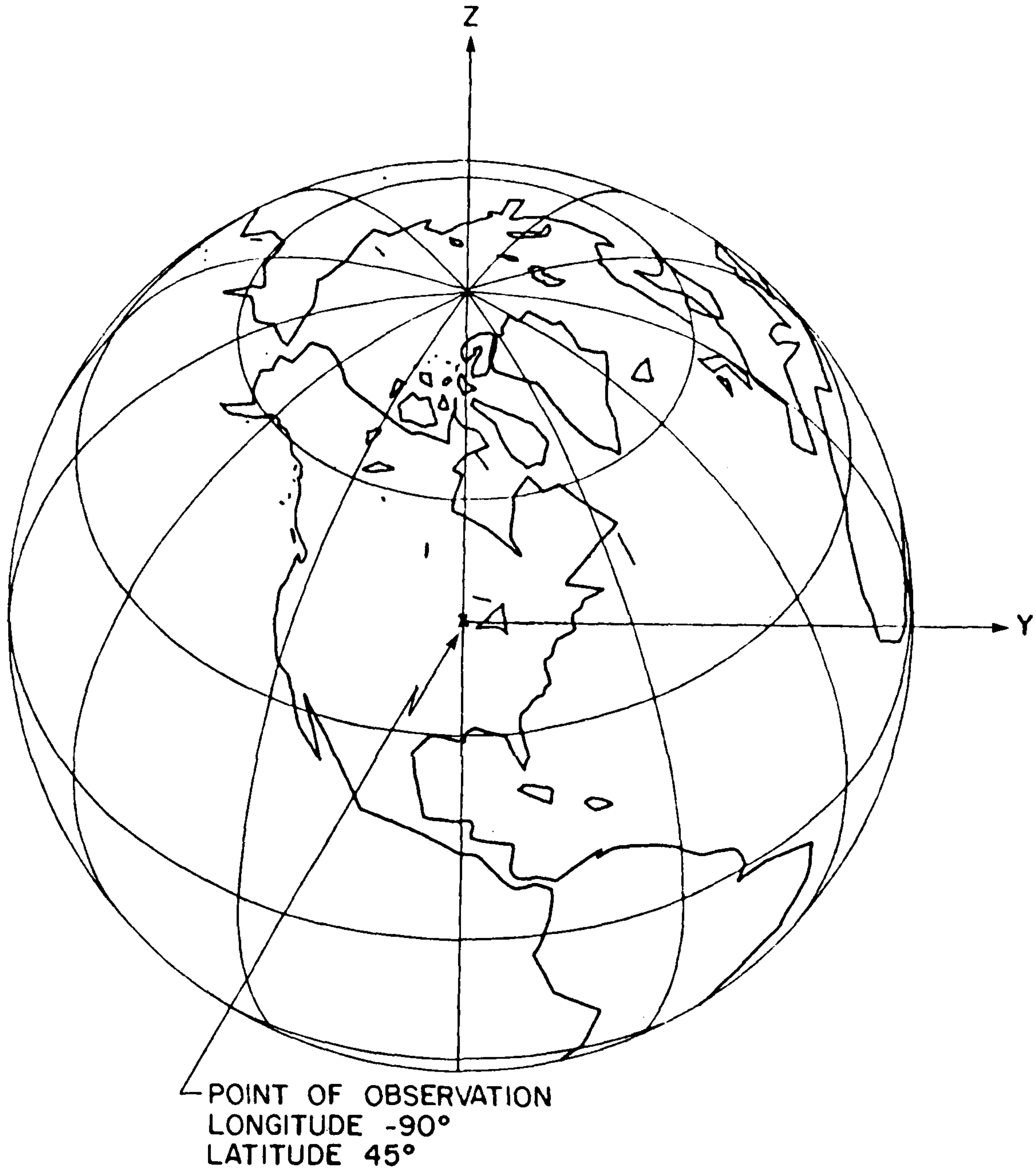


Figure 6: Topocentric system of coordinates

Description of the systems of coordinates

ERF: fixed system of rectangular coordinates centered on the Earth. The origin of the system is tied to the center of the Earth and the system of axis does not rotate with the Earth. The Z axis is pointing to the North Pole and the X axis, at time t=0, is pointing towards the point with longitude 0 and latitude 0. The movement of the Earth around the Sun is neglected because the simulation is to be used for short periods of time going from a few minutes to one day (see Fig. 2).

ESF: fixed system of spherical coordinates where R, Θ and ϕ are defined in the usual way from ERF, ϕ is measured from the Z axis (see Fig. 2).

ERR: rotating system of rectangular coordinates. The origin of the system is tied to the center of the Earth and the system of axis does rotate with the Earth. The Z axis is pointing towards the point with longitude 0 and latitude 0 all the time.

ESR: rotating system of spherical coordinates where R, Θ and f are defined in the usual way from ERR, ϕ is measured from the Z axis (see Fig. 2).

ERE: fixed system of rectangular coordinates. The origin is at the center of the Earth, the Z axis is perpendicular to the orbital plane of the satellite and the X axis is pointing towards the perigee. The satellite turns in the positive direction.

ESE: fixed system of spherical coordinates. Where R, 0 and ϕ are defined in the usual way from ERE. ϕ is measured from the Z axis and Θ is the true anomaly (see Figs. 3 and 10).

EGR: rotating system of geographic coordinates. The origin is tied to the center of the Earth, the radial distance is measured from the origin. The latitude is positive in the Northern Hemisphere and negative in the Southern Hemisphere. The positive direction for the longitude is Eastward (see Fig. 4).

SRT: rectangular and topocentric system of coordinates centered on the satellite. The X axis is pointing away from the center of the Earth and the Z axis is pointing Northward (see Fig. 3 and 6).

SST: spherical system of coordinates centered on the satellite where R, 0 and ϕ are defined in the usual way from SRT. ϕ is measured from the Z axis (see Fig. 1).

SXT: spherical system of coordinates centered on the satellite where R, Θ and ϕ are defined from SRT, according to Fig. 5. ϕ is measured from the X axis.

SRE: rectangular system of coordinates centered on the satellite. Z is perpendicular to the orbital plane and Y is tangent to the orbit (see Fig. 7).

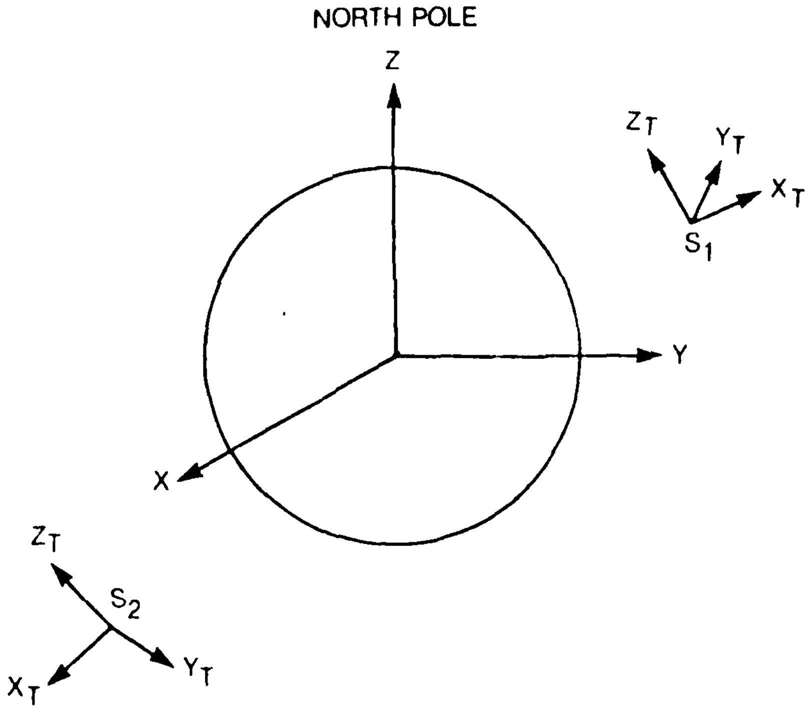


Figure 7: System of coordinates used to calculate the coverage area of the mechanical scanning system

SXE: spherical system of coordinates centered on the satellite where R, θ and ϕ are defined from SRE according to Fig. 5. ϕ is measured from the X axis.

ORR: rotating topocentric rectangular system of coordinates. The origin of the system is at the point of observation. The X axis is pointing away from the center of the Earth and the Z axis is pointing Northward (see Fig. 6).

Units

The units used in that workspace are:

- for the time: minutes
- for distance: kilometers
- for angle: degree
- for speed: kilometers/minute.

Description of the input variables

SYSAT: contains the parameters of the satellite orbits and the type of radar set carried by the satellite. The format of SYSAT is illustrated in Figure 8. The type of scanning performed by the radar is set in column 10: 0 stands for electronic scanning and 1 stands for mechanical scanning (see Fig. 8).

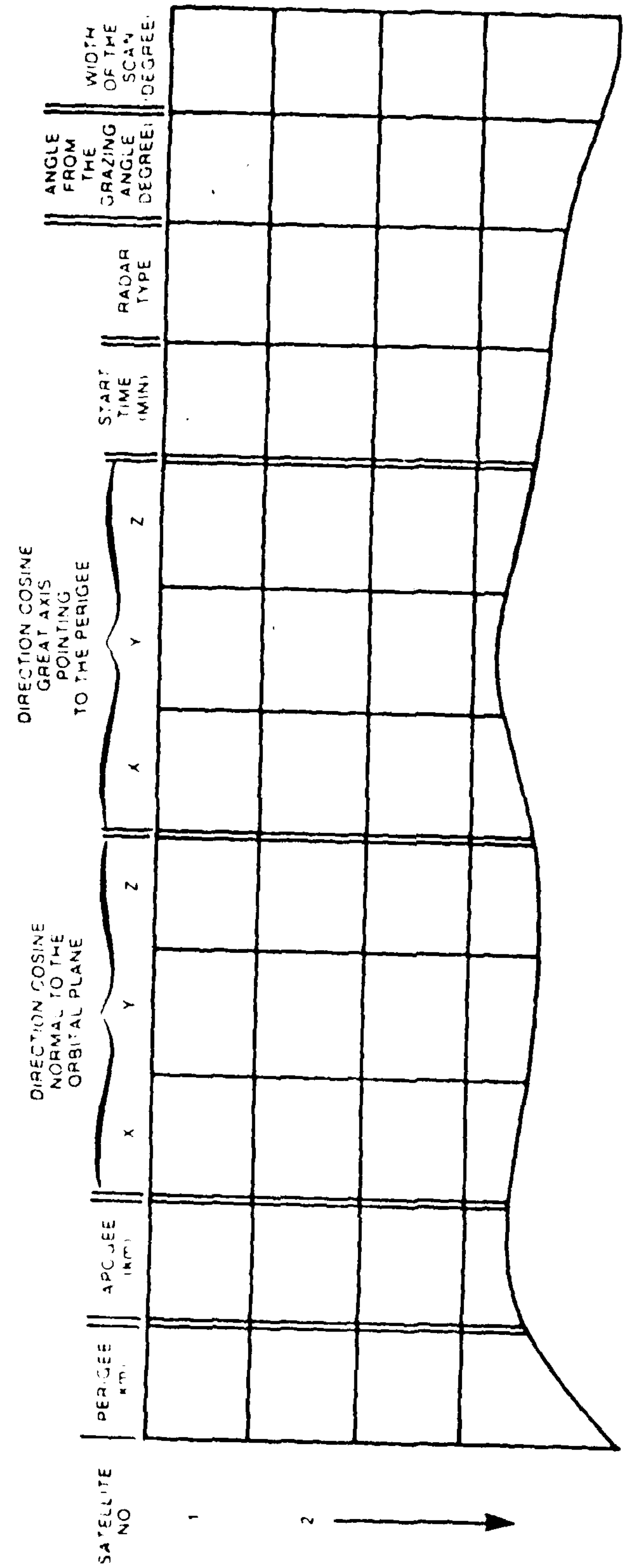


Figure 8: Format of the SYSAT array

Documentation of the programs

The documentation of the programs contains, for each program, the list of the input variable, their dimension, their nature, their source program, system of coordinates and units. A list of the output variables, their dimensions, their nature, their destination program, the system of coordinates and their units is also provided. It is also stated, for every variable, between the parenthesis following its name, if the variable is global (G), local dummy (LD) or local result (LR).

ANGR

Function: calculates the polar angle associated to a vector who has certain component X and Y.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
AX(LD)	number	X component of the vector	TVRCSP ANGROT	rectangular	unitless
AY(LD)	number	Y component of the vector	TVRCSP ANGROT	rectangular	unitless

ANGR

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
ARED(G)	number	polar angle associated to the components X and Y of a vector	ANGROT TVRCSD	-	radians

ANGRV

Function: calculates the polar angle associated to each vector having certain components X and Y.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
AX(LD)	vector	contains the X components of the vectors	TRECSPX	rectangular	unitless
AY(LD)	vector	contains the Y components of tne vectors	TRECSPX	rectangular	unitless

ANGRV

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
AREP(LR)	vector	contains the polar angle of the vectors	TRECSPX	-	radian

ANGROT

Function: calculates the three rotations around the axis Y, X and Z that are needed to go from a system XYZ to a system X'Y'Z' (see Fig. 9). The rotation matrix necessary to make the transformation and the inverse transformation are calculated.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
VZ(LD)	vector (3)	coordinates of Z' in the XYZ system	*	rectangular	unitless
VX(LD)	vector (3)	coordinates of X' in the XYZ system	*	rectangular	unitless
AREP(G)	number	angle associated to a vector having a certain X and Y coordinate.	ANGR	-	radians
RX(G)	3 x 3	Matrix of rotation that executes a rotation of PHX around the X axis.	RAX	rectangular	unitless
RY(G)	3 x 3	Matrix of rotation that executes a rotation of PHY around the Y axis.	RAY	rectangular	unitless
RZ(G)	3 x 3	Matrix of rotation that executes a rotation of PHZ around the Z axis.	RAZ	rectangular	unitless

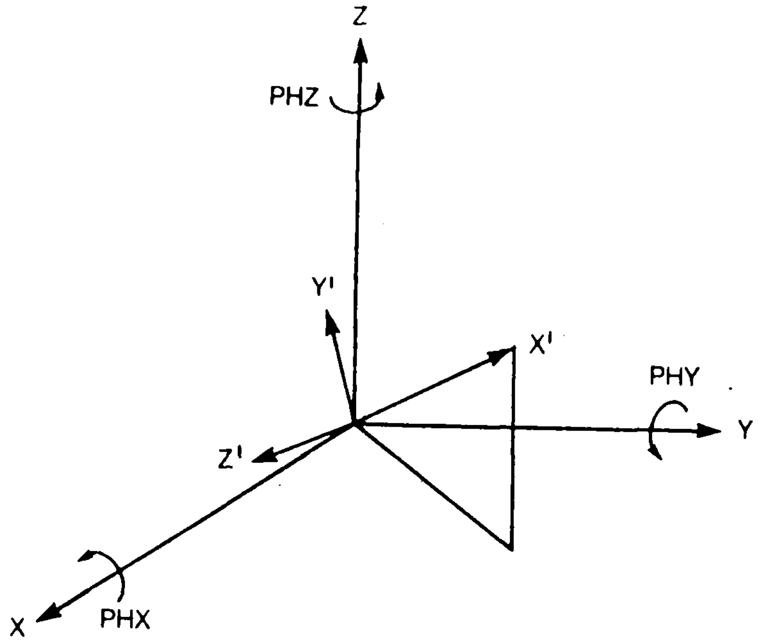


Figure 9: Rotations necessary to perform a transformation of coordinates

ANGROT

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MR(G)	(3 x 3)	matrix of rotation that transforms X'Y'Z' into XYZ	*	rectangular	unitless
IMR(G)	(3 x 3)	matrix of rotation that transforms XYZ into X'Y'Z'	*	rectangular	unitless

*The routine ANGROT is used by the programs: BAR, OPO, POSSAT, TOPO, TOPOF.

BROWNS

Function: calculates the angle f (the true anomoly, see Fig. 10) associated to an input vector containing various time for a certain orbit.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
MT(LD)	vector(NT)	contains the time	POSSAT	-	minutes
E(G)	vector(NS)	eccentricity of the orbit	POSSAT	-	unitless
NT(G)	number	number of time point	POSSAT	-	unitless
NS(G)	number	number of satellite	POSSAT	-	unitless

BROWNS

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
f*(LR)	vector(NT)	true anomoly	POSSAT	ESE	radians

*f is given by a trascendental equation: the Brown's method, as described in reference 1, has been used to solve T.

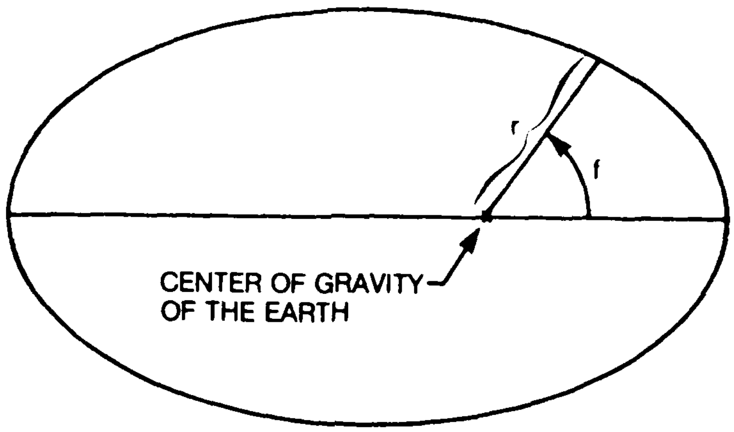


Figure 10: Definition of the true anomaly f

COURBE

Function: draws the curve specified by the vector VV.

Input Variables	Dimensions	Nature	Source
VV(LD)	vector of any length	contains the points to be plotted	user definition

no output variable

EARTH

Function: draws a circle that represents the Earth. That program has no input and no output variables.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
RREF(3)	(10 x 3)	contains the location of the reference points	CONTROL	ESR	kilometer radian

no output variable

HISTO

Function: draws the histogram of a vector

Input Variables	Dimensions	Nature	Source
VV(LD)	vector of any length	contains the values contributing to the histogram	user definition

no output variable

OPO

Function: calculates the matrix of rotation that transforms a ERF into a SRT or vice versa

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PO(LD)	vector (3)	position of the origin of the SRT system in the ERF system	CONTROL POSSAT	ERF	km.
IMR(G)	(3 x 3)	matrix of rotation to transform ERF into SRT	ANGROT	-	unitless

OPO

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MRO(LR)	(3 x 3)	matrix of rotation to transform ERF into SRT or ERF into ORR	CONTROL	-	unitless
MR(G)	(3 x 3)	matrix of rotation to transform SRT into ERF	POSSAT	-	unitless

POSSAT

Function: calculates the position of the satellite in the ERF and the ORR system of coordinate. It also calculates translations and matrix of rotation to be used in later calculations.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PT(LD)	vector(3)	vector containing the starting time, the time interval and the termination time of the simulation	CONTROL	-	minutes
SYSAT(G)	(NS, 11)	contains the parameters of the orbit of the satellites	user defined	-	see Fig. 7
F(G)	(NS,NT)	true anomoly	BROWNS	-	radians
MR(G)	(3 x 3)	matrix to go from the ERE to the ERF system (line 12)	ANGROT	-	unitless
MR(G)	(3 x 3)	matrix to go from the SXT to the ERF system (line 13)	OPO	-	unitless
MR(G)	(3 x 3)	matrix to go from the SXT to the ERE system (line 14)	ANGROT	-	unitless
MRO(G)	(NTx3x3)	matrix to go from the ERF to the ORR system	TOPO	-	unitless
XDR,YDR ZDR(G)	number	translation to go from ERF to ORR	TOPO	-	km

POSSAT

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MRO(G)	(NT,3,3)	matrix to go from the ERF to the ORR system.	POSSAT TDE, TDM	-	unitless
MTR(G)	(NT,NS,3)	translation to go from ERF to ORR	POSSAT TDE, TDM, TFM, TFE	-	unitless
PSG(G)	(3,NS,NT)	satellite position in the ERF system	CONTROL	-	km
PSO(G)	(3,NS,NT)	satellite position in the ORR system	CONTROL	-	km
MRS(G)	(NS,NT,3,3)	matrix to go from the SXT to the ERF system	TDE, TDM	-	unitless
MRSE(G)	(NS,NT,3,3)	matrix to go from the SXE to the ERE system	TDM	-	unitless

RAX

Function: to produce a matrix of rotation of an angle AR around the X axis.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
AR(LD)	number	angle of rotation	ANGROT	-	radians

RAX

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
RX(G)	3 x 3	matrix of rotation of an angle AR around the axis XI.	ANGROT	-	unitless

RAY

Function: to produce a matrix of rotation of an angle AR around the Y axis.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
AR(LD)	number	angle of rotation	ANGROT	-	radian

RAY

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
RY(3)	(3 x 3)	matrix of rotation of an angle AR around the axis Y.	ANGROT	-	unitless

RAZ

Function: to produce a matrix of rotation of an angle AR around the Z axix.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
AR(LD)	number	angle of rotation	ANGROT	-	radians

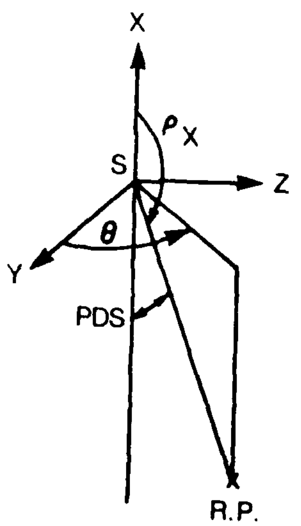
RAZ

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
RZ(G)	3 x 3	matrix of rotation of an angle AR around the axis Z	ANGROT	-	unitless

Function : to transform the coordinate of the reference points from the ESR system to the SSX system

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
VPS(G)	vector (3)	origin of the SSX system (position of the satellite)	CONTROL	ERF	km.
PRS(LO)	10 x 3	position of the reference points	CONTROL	[illegible]	km.
T(G)	number	time	CONTROL	-	min.
PRS(G)	10 x 3	position of reference points	TSPHREC	ERR	km.
PRS(G)	10 x 3	position of reference points	VOPOC	SRT	km.
PSX(G)	10 x 3	position of reference points	TRECSPX	SXT	km. radians

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
PSX(G)	10 x 3	position of reference points	CONTROL STATE	SXT	km. radians
PDS(G)	vector (10)	angle between the nadir and the azimuth position of the reference point (see Fig. 11)	CONTROL STATE	SXT	radians



S = POSITION OF THE SATELLITE, ORIGIN OF THE SYSTEM OF COORDINATE
R.P. = REFERENCE POINT

Figure 11: A reference point as seen from the satellite using the SXT or the SXE system of coordinates

PRSM

Function: to transform the coordinate of the reference points from the ESR system to the SSE system

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
VPS(LD)	vector (3)	origin of the SSE system (position of the satellite)	CONTROL	ERF	km.
PRS(LD)	10 x 3	position of reference points	CONTROL	ESF	km.
T(G)	number	time	CONTROL	-	min.
PRS(G)	10 x 3	position of reference points	TSPHREC	ERR	km.
PRS(G)	10 x 3	position of reference points	VOPOE	SRE	km.
PSX(G)	10 x 3	position of reference points	TRECSPX	SXE	km., radians

PRSM

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
PSX(G)	10 x 3	position of reference points	CONTROL STATM	SXE	km., radians
PDS(G)	vector (10)	angle between the nadir and the azimuth position of the reference point (see Fig. 11)	CONTROL STATM	SXE	radians

STATE

Function: Establish, for the electronic scanning mode, if the reference points are within or out of the coverage area. The revisit time and the number of revisits are calculated when needed.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PSX(G)	(10, 3)	position of reference points	PRSE CONTROL	SXT	km., radians
PDS(G)	vector (10)	angle between the nadir and the azimuth position of the reference points	CONTROL PRSE	SXT	radians
VGAN(G)	vector (10)	angle between the nadir and the outside border of the coverage area	TFE	SXT	radians
RDMAX(G)	vector (10)	distance between the satellite and the plane containing the outside border of the coverage area	TFE	SRT	km.

STATE

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
NREV(G)	vector (10)	each component contains the number of revisits associated to the corresponding reference point.	-	-	-
REV1(G)	vector	revisit time for reference point 1	-	-	min.
REV2(G)	"	" 2	-	-	"
REV3(G)	"	" 3	-	-	"
REV4(G)	"	" 4	-	-	"
REV5(G)	"	" 5	-	-	"
REV6(G)	"	" 6	-	-	"
REV7(G)	"	" 7	-	-	"
REV8(G)	"	" 8	-	-	"
REV9(G)	"	" 9	-	-	"
REV0(G)	"	" 10	-	-	"

STATM

Function: Establish, for the mechanical scanning mode, if the reference points are within or out of the coverage area. The revisit time and the number of revisits are calculated when needed.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PSX(G)	(10, 3)	position of reference points	PRSM CONTROL	SXE	km., radians
PDS(G)	vector (10)	angle between the nadir and the azimuth position of the reference points	CONTROL PRSM	SXE	radians
VGAN(G)	vector (10)	angle between the nadir and the outside border of the coverage area	TFM	SXE	radians
RDMAX(G)	vector (10)	distance between the satellite and the plane containing the outside border of the coverage area	TFM	SRE	km.
WSCAN(G)	vector (10)	width of the scan line	user defined in SYSAT	SXE	degrees

STATM

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
NREV(G)	vector (10)	each component contains the number of revisits associated to the corresponding reference point.	-	-	-
REV1(G)	vector	revisit time for reference point 1	-	-	min.
REV2(G)	"	" 2	-	-	"
REV3(G)	"	" 3	-	-	"
REV4(G)	"	" 4	-	-	"
REV5(G)	"	" 5	-	-	"
REV6(G)	"	" 6	-	-	"
REV7(G)	"	" 7	-	-	"
REV8(G)	"	" 8	-	-	"
REV9(G)	"	" 9	-	-	"
REV0(G)	"	" 10	-	-	"

SYSVEC

Function: to calculate from an initial vector a system of vectors located at AN degrees from each other. That routine may be used to find the parameters to be put in SYSAT as direction cosine of the normal to the orbit.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
V(I,D)	vector (3)	initial vector		ERF	
N(I,D)	number	number of vectors			
AN(I,D)	number	angle between the vectors (degrees)			

SYSVEC

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
S(G)	N X 3	each row contains one of the new vectors		ERE	

TDE

Function: calculates the position of the borders of the coverage area and displays them (electronic scanning) See Figures 12 and 13.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
RC(G)	number	distance from the satellite to the center of the Earth	TFE CONTROL	-	km.
XRC(G)	vector (2)	distance between the center of the Earth and the planes containing the boundaries of the coverage area	TFE CONTROL	-	km.
RRC(G)	vector (2)	radius of the boundaries of the coverage area	TFE CONTROL	-	km.
MRS(G)	NSxNTx3x3	matrix to go from the SRT to the ERF system	POSSAT	-	-
MRO(G)	NTx3x3	matrix to go from the ERF to the ORR system	POSSAT	-	-
TRSO(G)	vector (3)	translation to go from a SRT to a ORR system	TFE	-	km.
IS	number	index of the satellite	CONTROL	-	-
IN	number	index of the time point	CONTROL	-	-

No output variable

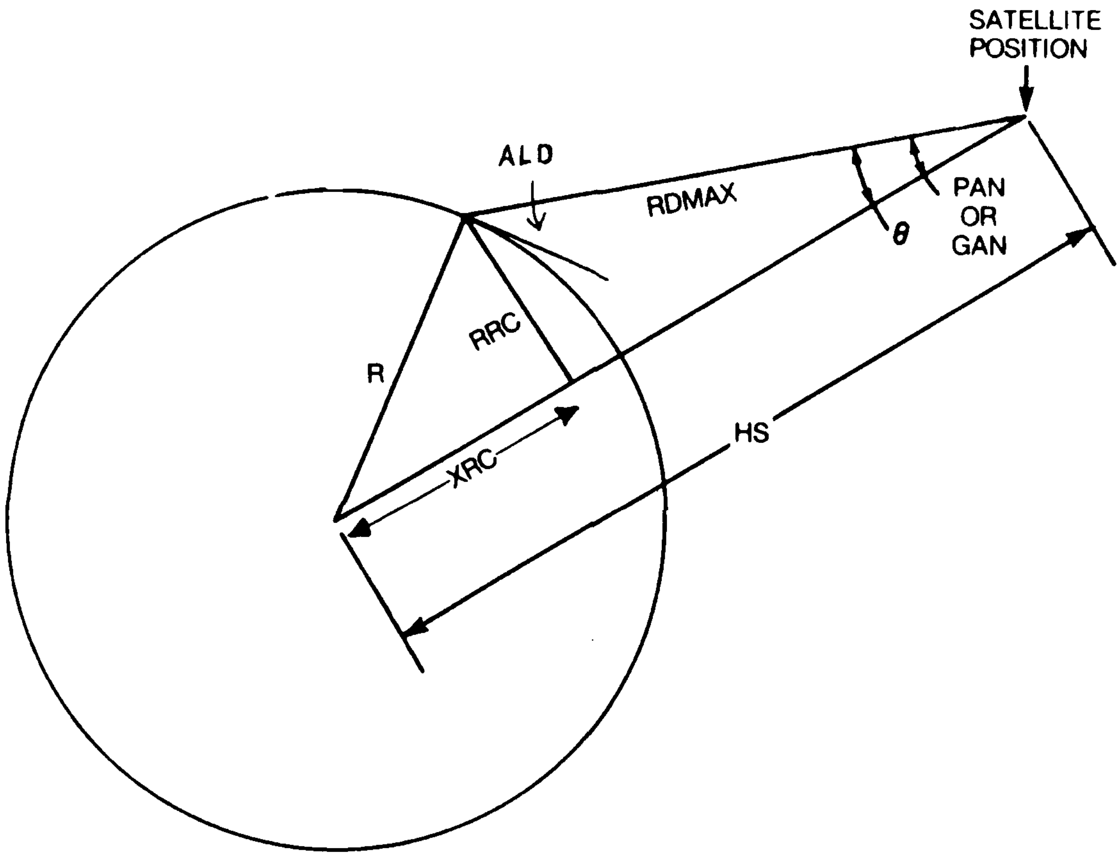


Figure 12: Parameters used in the calculation of the coverage area

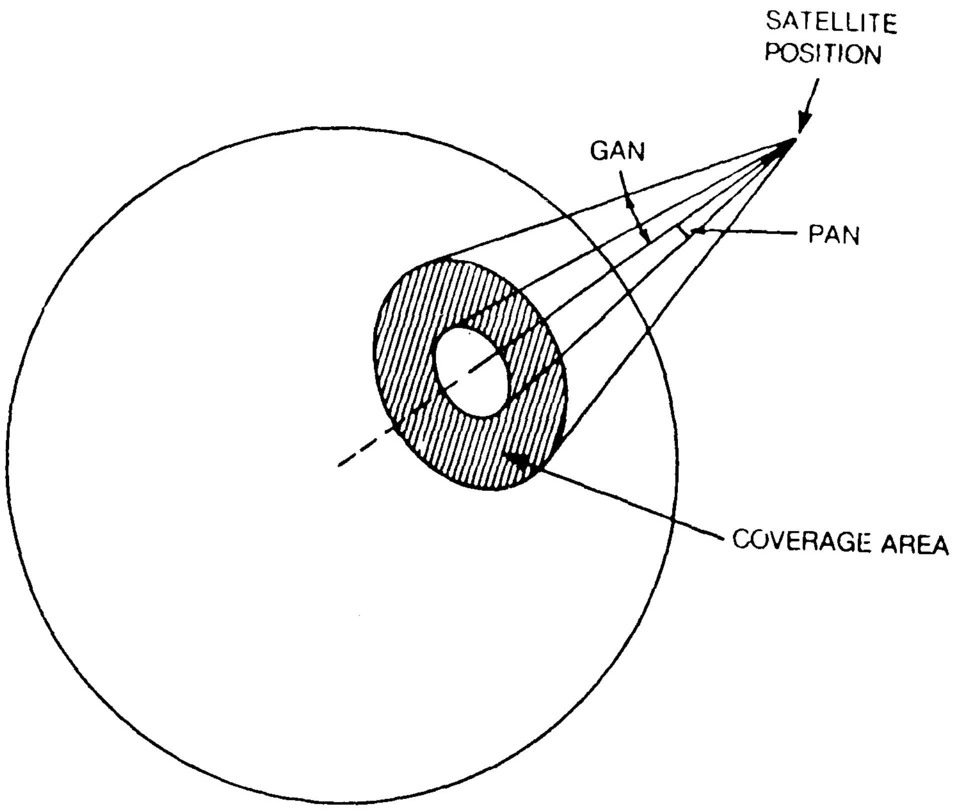


Figure 13: Electronic coverage area

TDM

Function: calculates the position of the borders of the coverage area and displays them (mechanical scanning) (see Figure 14).

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
WSCAN	number	angular width of the scan	user def. in SYSAT	-	degrees
XRC*(G)	vector (2)	distance between the center of the Earth and the planes containing the boundaries of the coverage area*	TFM	SRT	km.
RRC*(G)	vector (2)	radius of the boundaries of the coverage area	TFM	-	km.
MRSE(G)	NSxNTx3x3	matrix to go from the SRE to the ERF system	POSSAT	-	-
MRO(G)	NTx3x3	matrix to go from the ERF to the ORR system	POSSAT	-	-
TRSO(G)	vector (3)	translation to go from a SRT to a ORR system	TFM	-	km.
IS	number	Index of the satellite	CONTROL	-	-
IN	number	Index of the time point	CONTROL	-	-

No output variable

*see Figure 12

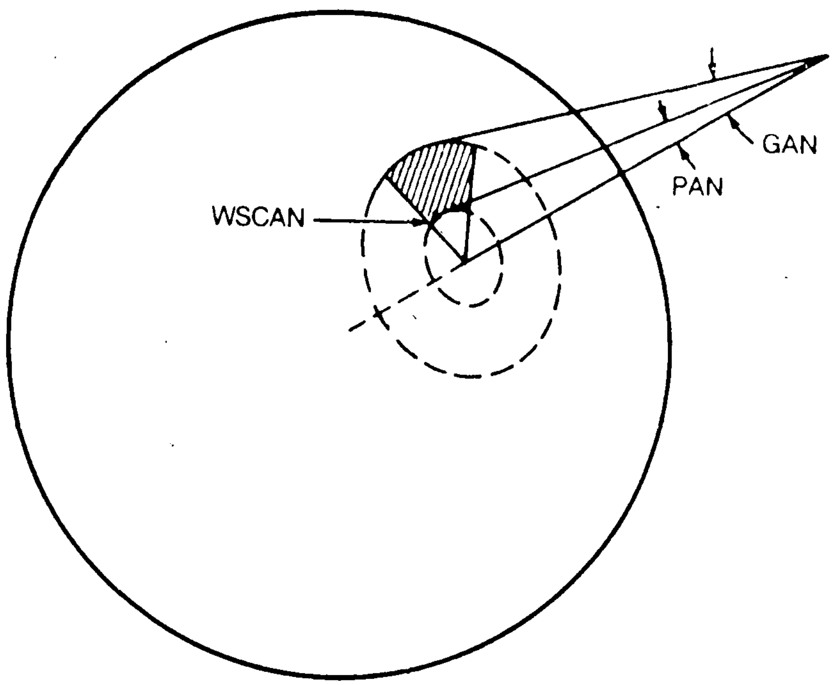


Figure 14: Mechanical coverage area

TFE

Function: calculates some of the parameters used in the calculation of the position of the borders of the coverage areas for the electronic scanning

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PSS(G)	(3,NS,NT)	position of the satellite	POSSAT	ERF	km.
ALO(G)	number	angle from the grazing angle for the outside border of the coverage area	CONTROL	-	radians
R(G)	number	radius of the Earth	CONTROL	-	km.
NS(G)	number	number of satellites		-	-
NT(G)	number	number of time points		-	-
IS	number	index of the satellite	CONTROL	-	-
IN	number	index of the time point	CONTROL	-	-

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
[illegible]AN+(G)	number	angle from the grazing angle for the inside border of the coverage area**	STATE	-	radians
GAN+(G)	number	angle from the grazing angle for the outside border of the coverage area**	STATE	-	radians
XRC*(G)	vector (3)	distance between the center of the Earth and the planes containing the boundaries of the coverage area*	TDE	-	km.
RRC*(G)	vector (3)	radius of the boundaries of the coverage area	TDE	-	km.
RDMAX*(G)	number	distance between the satellite and the outside border of the coverage area	STATE	-	km.

** see Figure 12

* see Figure 14

FEM

Function: calculates some of the parameters used in the calculation of the position of the borders of the coverage areas for the mechanical scanning (see Figures 12 and 14)

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PSS(G)	(3,NS,NT)	position of the satellite	POSSAT	ERF	km.
AOD(G)	number	angle from the grazing angle for the outside border of the coverage area	CONTROL	-	radians
R(G)	number	radius of the Earth	CONTROL	-	km.
NS(G)	number	number of satellites		-	-
NT(G)	number	number of time points		-	-
IS	number	index of the satellite	CONTROL	-	-
IN	number	index of the time point	CONTROL	-	-

TDM

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
PAN(G)	number	angle from the grazing angle for the inside border of the coverage area	STATM	-	radians
GAN(G)	number	angle from the grazing angle for the outside border of the coverage area	STATM	-	radians
XRC(G)	vector (2)	distance between the center of the Earth and the planes containing the boundaries of the coverage area	TDM	-	km.
RRC(G)	vector (2)	radius of the boundaries of the coverage area	TDM	-	km.
RDMAX(G)	number	distance between the satellite and the outside border of the coverage area	STATM	-	km.

TGEOSPH

Function: transforms a GEO system into a ESR system.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
MC(LD)	N* x 3	coordinate of a point in the GEO system	BAR	ESR	km: degrees

TGEOSPH

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MRC(LR)	N* x 3	coordinate of a point in the ESR system	BAR	ESR	km; radians

*N = any integer number greater or equal to 1.

TOPO

Function: calculates the matrix of rotation needed to transform a ESR into a ERF and the reverse.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PO(LD)	vector (3)	position vectors	POSSAT	ESR	km, radians
VT(LD)	number	time	POSSAT	-	min

TOPO

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MRO(LD)	3 x 3	rotation matrix to go from ESR to ERF	POSSAT		
XD			POSSAT	ERF	km
XDR,YDR ZDR(G)		translation to go from ERT to ORR	POSSAT	ERF	km
ZD			POSSAT	ERF	km

TRECSPX

Function: transforms rectangular coordinates into spherical coordinates (see Fig. 5) with the angle ϕ measured from the X axis.

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
FSR(LD)	N* x 3	rectangular coordinates	PRSE PRSM	rectangular	km
AREP(G)	number	angle	ANGRV	-	radians

*N is an integer number greater or equal to 1.

TRECSPX

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
PSX(LR)	N* x 3	spherical coordinates	PRSE PRSM	spherical	km, radians

*N is an integer number greater or equal to 1.

TSPHREC

Function: transforms spherical coordinates (in an array) into rectangular coordinates (see Fig. 2)

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
MC(LD)	N* x 3	spherical coordinates	BAR PRSE PRSM	-	km, radians

TSPHREC

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MCC(LR)	N* x 3	rectangular coordinates	BAR PRSE PRSM	-	km

*N is an integer number greater or equal to 1.

TVRCSP

Function: transforms rectangular coordinates (in a vector) into spherical coordinates (see Fig. 2).

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
FSR(LD)	vector(3)	vector in rectangular coordinates	BAR	-	-
AREP(G)	number	angle	ANGR	-	radians

TVRCSP

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
PSX(LR)	vector (3)	vector in spherical coordinates	BAR	-	-

TVSPRC

Function: transforms spherical coordinates (in a vector) into rectangular coordinates (see Fig. 2).

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
PO(LO)	vector(3)	vector in spherical coordinates	CONTROL	-	-

TVSPRC

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
TRF(LR)	vector(3)	vector in rectangular coordinates	CONTROL	-	-

VOPOC

Function. transforms a vector MCR from the ERF system
to the SXT system

N = number of lines of the array MCR

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
MCR(LD)	N x 3	vector to be transformed	PRSE	ERF	km.
VPS(LD)	vector (3)	satellite position	PRSE	ERF	km.
PO(G)	vector (3)	satellite position	TVRCSP	ESF	km., radians
MRS(G)	(IS,IN,3,3)	matrix of rotation to go from the SXT to the ERF system	POSSAT	-	-

VOPOC

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MPT(LR)	N x 3	coordinate of the final vector	PRSE	SXT	km.

VOPOE

Function: transforms a vector MCR from the ERF system to the SXT system

N = number of lines of the array MCR

Input Variables	Dimensions	Nature	Source program	System of Coordinates	Units
MCR(LD)	N x 3	vector to be transformed	PRSM	ERF	km.
VPS(LD)	vector (3)	satellite position	PRSM	ERF	km.
PO(G)	vector (3)	satellite position	TVRCSP	ESF	km., radians
MRSE(G)	(IS,IN,3,3)	matrix of rotation to go from the SXE to the ERF system	POSSAT	-	-

VOPOE

Output Variables	Dimensions	Nature	Destination program	System of Coordinates	Units
MPT(LR)	N x 3	coordinate of the final vector	PRSM	SXT	km.

Conclusions

We described two complementary software packages designed to perform studies of time of revisits of satellite system. Input and output variables of every routine were described, examples of the output were given and a block diagram of the CONTROL program of each package was presented.

References

1. I.R. Deutsch, Orbital Dynamics of Space Vehicles, Prentice Hall, 1963, p. 3-27.

2. W.R. Corliss, Scientific Satellites, NASA SP-133, 1967, p. 93-110.

APPENDIX I

LIST OF PROGRAMS

APPENDIX I

List of Programs:

The workspace TSATCO contains the following programs: The DRAW package of APL plus, ANGR, ANGROT, ANGRV, BROWNS, CONTROL, COURBE, EARTH, HISTO, OPO, POSSAT, PRSE, PRSM, RAX, RAY, RAZ, STATE, STATM, SYSVEC, TDF, TFF, TFM, TGEOSPH, TOPO, TRECSPX, TSPHREC, TVRCSP, TVSPRC, VOPOC, VOPOE.

The workspace SATCO contains the same programs as the workspace TSATCO except that the program CONTROL, STATE and STATM differs from the programs having the same name in SATCO.

APPENDIX II

LISTING OF THE PROGRAMS

TSATCO

```
      ∇ANGROT[⎕]∇
    ∇ VZ ANGROT VX;AREP
[1]   →((+/(VX×VZ))≠0)/L50
[2]   →((+/(VZ×VZ))≠1)/L51
[3]   →((+/(VX×VX))≠1)/L52
[4]   CNX←VZ[1];CNY←VZ[2];CNZ←VZ[3];CAX←VX[1];CAY←VX[2];CAZ←VX[3]
[5]   CBX←(CNY×CAZ)-(CAY×CNZ);CBY←(CAX×CNZ)-(CNX×CAZ);CBZ←(CNX×
      CAY)-(CAX×CNY)
[6]   VY←CBX,CBY,CBZ
[7]   →((|CNZ)=1)/L20
[8]   →((|CAZ)=1)/L30
[9]   →((|CBZ)=1)/L40
[10]  →(CBZ=0)/L70
[11]  →(CAZ=0)/L80
[12]  VXP←VXP÷((+/(VXP×VXP))*0.5);VXP←VSX×(CBY,CBX,0);VSX←((1 ¯1
      0)×(CAY≥0))+((¯1 1 0)×(CAY<0))
[13]  DENO←((CBX×CBX)+(CBY×CBY))*0.5
[14]  TYP←AREP;CBX ANGR CBY;TXP←AREP;VXP[1]ANGR VXP[2]
[15]  SZ←(TYP>TXP)×(1-SZZ);SZZ←(TYP≥(3×PI÷2))∧(TYP≤(2×PI))∧(TXP≤(
      PI÷2))
[16]  SZ←((TXP≥(3×PI÷2))∧(TXP≤(2×PI))∧(TYP≤(PI÷2)))+SZ
[17]  PHY←(+/((SZ=1),-(SZ=0)))×((CAZ≥0)-(CAZ<0))×PHY;PHY←¯2○(+/(
      VX×VXP))
[18]  PHX←((AREP×((CBZ<0)-(CBZ≥0)))×(SZ=1))+(((CBZ<0)-(CBZ≥0))×(
      PI-AREP)×(SZ=0));DENO ANGR(|CBZ)
[19]  →L60;PHZ←-AREP;(VXP[1])ANGR(VXP[2])
[20]  L70:DENO←(((CAX×CAX)+(CAY×CAY))*0.5)
[21]  PHY←AREP×(×CAZ)×((CBX≥0)-(CBX<0))×((CAY≤0)-(CAY>0));DENO
      ANGR(|CAZ)
[22]  PHX←PI×(((CNZ≥0)×0)+(CNZ<0))
[23]  →L60;PHZ←-AREP;CAX ANGR CAY
[24]  L80:PHY←0
[25]  DENO←(((CBX×CBX)+(CBY×CBY))*0.5)×(+/((CBZ≥0),-(CBZ<0)))
[26]  PHX←-AREP;DENO ANGR CBZ
[27]  →L60;PHZ←-AREP;CAX ANGR CAY
[28]  L20:PHY←(0×(CNZ=1))+(PI×(CNZ=¯1));PHX←0
[29]  →L60;PHZ←-(AREP-(PI÷2));CBX ANGR CBY
[30]  L30:PHY←((PI÷2)×(CAZ=1))-((PI÷2)×(CAZ=¯1))
[31]  →L60;PHX←0;PHZ←(PI÷2)-AREP;CBX ANGR CBY
[32]  L40:PHZ←0;PHX←((PI÷2)×(CBZ=¯1))-((PI÷2)×(CBZ=1))
[33]  →L60;PHY←AREP×((CBZ=¯1)-(CBZ=1));CAX ANGR CAY
[34]  L50:→L91;'ERROR FROM ANGROT VZ AND VX ARE NOT PERPENDICULAR
      '
[35]  L51:→L91;'ERROR FROM ANGROT VZ IS NOT UNITARY'
[36]  L52:→L91;'ERROR FROM ANGROT VX IS NOT UNITARY'
[37]  L60:IMR←⌹MR;MR←(RY+.×RX+.×RZ);RAY PHY;RAX PHX;RAZ PHZ
[38]  →((|VT[1])≤0.9999)/L90;VT←VX+.×IMR
[39]  →((|VT[3])≤0.9999)/L90;VT←VZ+.×IMR
[40]  →L91;→((|VT[2])≤0.9999)/L90;VT←VY+.×IMR
```

TSATCO

```
      ∇ANGROT[⎕41]∇
[41]  L90:→L92;'ERROR FROM ANGROT IN THE ROTATION ANGLES'
[42]  L92:'VX=';VX
[43]  'VY=';VY
[44]  'VZ=';VZ
[45]  'PHY=';PHY
[46]  'PHX=';PHX
[47]  'PHZ=';PHZ
[48]  →;
[49]  L91:
```

```
      TSATCO
      ∇CONTROL[⎕]∇
    ∇ CONTROL;PERI;APO;LONR;LATR;B;L;RSS;XS;YS;ZS;COR;I;R;ZI2;
      SCF;TMP;TOP;TDP;NLIM;NCAL;INN;IN
[1]   'STARTING TIME OF THE SIMULATION='
[2]   TO←⎕
[3]   'TIME INCREMENT='
[4]   TI←⎕
[5]   'DURATION OF SIMULATION='
[6]   TM←TO+TD←⎕
[7]   'POSITION OF THE OBSERVATION POINT'
[8]   'ALTITUDE ABOVE EARTH SURFACE=0'
[9]   ROB←R+HR←0;R←6370
[10]  'LONGITUDE=0'
[11]  THOB←LONR×PI÷180;LONR←0
[12]  'LATITUDE=0'
[13]  PHOB←(PI÷2)-(LATR×PI÷180);LATR←0
[14]  PO←ROB,THOB,PHOB
[15]  NS←1↑(⍴SYSAT)
[16]  OME←0.00437;PREF[;3]←((⍳10)-1)×PI÷18;PREF←(10 3)⍴6370 0 0
[17]  NREV←10⍴0;ZI2←0;TREV←10⍴(TO-(3×TI)+1);TREVS←(NS,10)⍴0
[18]  REV1←REV2←REV3←REV4←REV5←REV6←REV7←REV8←REV9←REV0←0⍴0
[19]  BOX;WINDOW 0 6.2 0 6.2;STRAPIS 7;SCALE((-SCF),SCF,(-SCF),
      SCF);SCF←(SYSAT[1;1]+SYSAT[1;2]+(2×6370))÷2
[20]  EARTH;MRF←OPO PO
[21]  POR←TVSPRC PO;MTO←MRF
[22]  NCAL←TD÷TI;NLIM←9;TDP←TD;INP←1;TOP←TO;TMP←TM;T←TO;IN←INN←1
[23]  L30:→(NCAL≥NLIM)/L20
[24]  TMP←TM;TOP←T;TDP←NCAL×TI
[25]  →L25;'TOP=';TOP;'    TMP=';TMP;POSSAT(TOP,TI,TDP)
[26]  L20:TOP←T
[27]  POSSAT(TOP,TI,TDP);TMP←TOP+(NLIM×TI);TDP←NLIM×TI
[28]  L25:T←TOP;IN←1;IS←1
[29]  L15:→(INN=1)/L17
[30]  →(IN=1)/L50
[31]  →(PSO[1;IS;IN]≤(-PO[1]))/L91
[32]  →L17;0 DRAW(PSO[3;IS;IN-1],PSO[3;IS;IN])VS(PSO[2;IS;IN-1],
      PSO[2;IS;IN])
[33]  L50:→(PSO[1;IS;IN]≤(-PO[1]))/L91
[34]  0 DRAW(PSOZ[IS],PSO[3;IS;IN])VS(PSOY[IS],PSO[2;IS;IN])
[35]  L17:→(SYSAT[IS;10]=0)/L60
[36]  →L91;STATM;TFM;ALD←SYSAT[IS;11];WSCAN←SYSAT[IS;12];PSG[;IS;
      IN]PRSM PREF
[37]  L60:STATE;TFE;ALD←SYSAT[IS;11];PSG[;IS;IN]PRSE PREF
[38]  L91:→((IS←IS+1)≤NS)/L15
[39]  L11:→((T←T+TI)≤TMP)/L15;'T=';T+TI;IN←IN+1;IS←1;INN←INN+1
[40]  →(T≥TM)/L35
[41]  INP←INP+1
[42]  →L30;NCAL←NCAL-(NLIM+1);PSOZ←PSO[3;;(IN-1)];PSOY←PSO[2;;(
      IN-1)]
[43]  L35:
    ∇
```

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      TSATCO

      ∇COURBE[⎕]∇
    ∇ COURBE VV
[1]   VW←⍋VV;STRAPIS 5
[2]   L1←VV[VW[1]];L2←VV[VW[ρVW]]
[3]   L1←(L1×(L1<0))+(0×(L1≥0))
[4]   AXES;BOX;SCALE ¯1 10,L1,L2;WINDOW 0 6.2 0 6.2
[5]   VX←(⍳(ρVV))×10÷(ρVV)
[6]   0 DRAW VV VS VX
    ∇

      ∇EARTH[⎕]∇
    ∇ EARTH;ANG;X;Y;R;HMAR;I
[1]   ANG←(0,⍳100)×○1÷50;HMAR←R×2○PREF[;3];R←6370
[2]   X←R×2○ANG
[3]   Y←R×1○ANG
[4]   0 DRAW Y VS X;I←1
[5]   0 DRAW(0,R)VS(0,0)
[6]   L50:→((I←I+1)≤10)/L50;0 DRAW(HMAR[I],HMAR[I])VS(¯100,100)
    ∇

      ∇HISTO[⎕]∇
    ∇ HISTO VV
[1]   NE←10ρ0;STRAPIS 5
[2]   VW←⍋VV
[3]   RG←-VV[VW[1]]-VV[VW[ρVW]]
[4]   L2←L1+INC;L1←VV[VW[1]];J←1;INC←RG÷10
[5]   L11:→((J←J+1)≤10)/L11;L2←L2+INC;L1←L1+INC;NE[J]←+/((VV≥L1)∧
      (VV<L2))
[6]   AXES;BOX;SCALE 0 10 0,NMA;NMA←NE[ρNMA];NMA←⍋NE;WINDOW 0
      6.2 0 6.2
[7]   N←1
[8]   L13:→((N←N+1)≤10)/L13;0 DRAW VY VS VX;VY←0,NE[N],NE[N],0;
      VX←(N-1),(N-1),N,N
[9]   'HISTOGRAM VALUES=';NE
[10]  'MEAN=';MEAN;MEAN←(+/NE)÷(ρNE)
[11]  'MEAN SQUARE ERROR=';MSQ;MSQ←(+/((NE-MEAN)×(NE-MEAN)))÷(ρ
      NE)
    ∇

      ∇OPO[⎕]∇
    ∇ MRO←OPO PO;OME;THR;VX;VZ
[1]   VX←VZ←3ρ0
[2]   VX[1]←(1○PO[3])×2○PO[2];VX[2]←(1○PO[3])×1○PO[2];VX[3]←2○PO[
      3]
[3]   VZ[1]←-(2○PO[3])×2○PO[2];VZ[2]←-(2○PO[3])×1○PO[2];VZ[3]←1○
      PO[3]
[4]   VZ ANGROT VX
[5]   MRO←IMR
    ∇
```

TSATCO

```
      ∇POSSAT[⎕]∇
    ∇ POSSAT PT;R;L;I;ML;IS;PSE
[1]   MT←(NS,NT)ρMT;NS←1↑ρSYSAT;NT←ρMT;MT←PT[1],((PT[2]×⍳⌊(PT[3]÷
      PT[2]))+PT[1])
[2]   R←6370;PSG←PSO←(3,NS,NT)ρ0
[3]   A←((2×R)+SYSAT[;1]+SYSAT[;2])÷2
[4]   E←(A-(R+SYSAT[;1]))÷A;MRSE←(NS,NT,3,3)ρ0
[5]   L←A×(1-(E×E))
[6]   F←BROWNS MT;I←1;MRO←(NT,3,3)ρ0;MTR←(NT,NS,3)ρ0;MRS←(NS,NT,3
      ,3)ρ0
[7]   L20:→((I←I+1)≤NT)/L20;MTR[I;;]←(NS,3)ρ(XDR,YDR,ZDR);MRO[I;;
      ]←MT[1;I]TOPO PO
[8]   RSS←ML÷(1+(ME×2○F));ML←(⍉(NT,NS)ρA)×(1-(ME×ME))
[9]   IS←1;PSE←(NT,3)ρ0;
[10]  L10:PSE[;2]←RSS[IS;]×1○F[IS;];PSE[;1]←RSS[IS;]×2○F[IS;]
[11]  VNZ ANGROT(5↓(¯4↓SYSAT[IS;]));VNZ←2↓(¯7↓SYSAT[IS;])
[12]  PSG[;IS;]←⍉PSE+.×MR;I←1
[13]  L30:PSO[;IS;I]←(PSG[;IS;I]-MTR[I;IS;])+.×MRO[I;;];MRS[IS;I;
      ;]←MR;DU←OPO VPH←TVRCSP PSG[;IS;I]
[14]  MRSE[IS;I;;]←MR;VNZ ANGROT(VG÷((+/(VG×VG))*0.5));VG←PSG[;
      IS;I]
[15]  →((I←I+1)≤NT)/L30
[16]  →((IS←IS+1)≤NS)/L10
    ∇


      ∇PRSE[⎕]∇
    ∇ VPS PRSE PRS
[1]   PRS[;2]←PRS[;2]+(OME×T)
[2]   PRS←TSPHREC PRS
[3]   PRS←VPS VOPOE PRS
[4]   PSX←TRECSPX PRS
[5]   PDS←PI-PSX[;3]
    ∇


      ∇PRSM[⎕]∇
    ∇ VPS PRSM PRS
[1]   PRS[;2]←PRS[;2]+(OME×T)
[2]   PRS←TSPHREC PRS
[3]   PRS←VPS VOPOE PRS
[4]   PSX←TRECSPX PRS
[5]   PDS←PI-PSX[;3]
    ∇
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TSATCO

      ∇RAX[⎕]∇
    ∇ RAX AR
[1]   RX←3 3ρ1 0 0 0,(2○AR),(-1○AR),0,(1○AR),2○AR
    ∇

      ∇RAY[⎕]∇
    ∇ RAY AR
[1]   RY←3 3ρ(2○AR),0,(1○AR),0 1 0,(-1○AR),0,2○AR
    ∇

      ∇RAZ[⎕]∇
    ∇ RAZ AR
[1]   RZ←3 3ρ(2○AR),(-1○AR),0,(1○AR),(2○AR),0 0 0 1
    ∇
      ∇STATE[⎕]∇
    ∇ STATE;VPAN;VGAN;VRD;DFO;NTP;VIND;NJ;CA
[1]   VPAN←10ρPAN;VGAN←10ρGAN;VRD←10ρRDMAX
[2]   DFO←(PSX[;1]≤VRD)∧(PDS<VGAN)
[3]   NTP←+/DFO
[4]   →(NTP<1)/L5
[5]   TDE
[6]   VIND←DFO/(DFO×⍳10);J←1
[7]   L1:NJ←VIND[J]
[8]   CA←'ZI2'ΔFMT NJ
[9]   →(TRES≤(5×TI))/L6;TRES←T-TREVS[IS;NJ]
[10]  TREV[NJ]←T;TRE←T-TREV[NJ]
[11]  NREV[NJ]←NREV[NJ]+1;TREVS[IS;NJ]←T
[12]  DUMMY←⍎'REV',CA[1;2],'←REV',CA[1;2],',TRE'
[13]  L6:→((J←J+1)≤NTP)/L1
[14]  L5:
    ∇

      ∇STATM[⎕]∇
    ∇ STATM;VPAN;VGAN;VRD;DFO;NTP;VIND;NJ;CA
[1]   VPAN←10ρPAN;VGAN←10ρGAN;VRD←10ρRDMAX
[2]   DFO←(PSX[;1]≤VRD)∧(PDS<VGAN)∧((((2×PI)-PSX[;2])≤(WSCAN×PI÷
      360))∨(PSX[;2]≤(WSCAN×PI÷360)))
[3]   NTP←+/DFO
[4]   →(NTP<1)/L5
[5]   TDM
[6]   VIND←DFO/(DFO×⍳10);J←1
[7]   L1:NJ←VIND[J]
[8]   CA←'ZI2'ΔFMT NJ
[9]   →(TRES≤(5×TI))/L6;TRES←T-TREVS[IS;NJ]
[10]  TREV[NJ]←T;TRE←T-TREV[NJ]
[11]  NREV[NJ]←NREV[NJ]+1;TREVS[IS;NJ]←T
[12]  DUMMY←⍎'REV',CA[1;2],'←REV',CA[1;2],',TRE'
[13]  L6:→((J←J+1)≤NTP)/L1
[14]  L5:
    ∇
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      TSATCO

      ∇SYSVEC[⎕]∇
    ∇ SYSVEC
[1]   'INITIAL VECTOR='
[2]   V←⎕
[3]   'NUMBER OF VECTORS=';
[4]   N←⎕
[5]   'ANGLE (DEGREES) BETWEEN THE VECTORS=';
[6]   AN←⎕
[7]   'THE ROTATION IS AROUND THE AXIS Z'
[8]   S[1;]←V;S←(N,3)ρ0;I←1
[9]   L1:→((I←I+1)<N)/L1;S[(I+1);]←V+.×RZ;RAZ(AN×PI×I÷180)
[10]  S
    ∇

      ∇TDE[⎕]∇
    ∇ TDE
[1]   CD←20×PI÷180;J←1;YGTS←ZGTS←19ρ0
[2]   L11:COR←(XRC[J]-HS),RRC[J],0
[3]   IT←1;ZGTS[1]←COR[3];YGTS[1]←COR[2];COR←COR+.×MRO[IN;;];COR←
      COR+TRSO;COR←COR+.×MRS[IS;IN;;]
[4]   L10:ZTR←RRC[J]×1○ANT;YTR←RRC[J]×2○ANT;ANT←CD×IT
[5]   COR←(XRC[J]-HS),YTR,ZTR
[6]   ZGTS[IT+1]←COR[3];YGTS[IT+1]←COR[2];COR←COR+.×MRO[IN;;];
      COR←COR+TRSO;COR←COR+.×MRS[IS;IN;;]
[7]   →((IT←IT+1)≤18)/L10
[8]   →L16;→((J←J+1)≤2)/L11;⍝ DRAW ZGTS VS YGTS
[9]   L15:'ERROR FROM TEC VX AND VZ ARE NOT PERPENDICULAR'
[10]  L16:
    ∇

      ∇TDM[⎕]∇
    ∇ TDM
[1]   CTR←11 3ρ0;J←1;PTR←2 11 3ρ0
[2]   ANT←((⍳11)-6)×WSCAN×PI÷1800
[3]   L11:CTR[;2]←RRC[J]×2○ANT;CTR[;3]←RRC[J]×1○ANT;CTR[;1]←XRC[
      J]-HS
[4]   PTR[J;;]←((CTR+.×MRSE[IS;IN;;])+TRSO)+.×MRO[IN;;]
[5]   →((J←J+1)≤2)/L11
[6]   ZGTS←(PTR[1;;3]),(⌽PTR[2;;3]),(PTR[1;1;3])
[7]   YGTS←PTR[1;;2],(⌽PTR[2;;2]),PTR[1;1;2]
[8]   ⍝ DRAW ZGTS VS YGTS
    ∇
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TSATCO

      ∇TFE[⎕]∇
    ∇ TFE
[1]   HS←(+/(PSG[;IS;IN]×PSG[;IS;IN]))*0.5
[2]   PAN←¯1○(R×(1○(5×PI÷6))÷HS);GAN←¯1○(R×(1○((PI÷2)+ALD))÷HS);
      ALD←ALD×PI÷180
[3]   BRC←HS×3○(PAN,GAN)
[4]   MRC←-3○(PAN,GAN)
[5]   XRC←((-BRC×MRC)+(((R×R)+(MRC×MRC×R×R)-(BRC×BRC))*0.5))÷((1+
      (MRC×MRC)))
[6]   RRC←(MRC×XRC)+BRC;TRSO←PSG[;IS;IN]-MTR[IN;IS;]
[7]   RDMAX←(((HS-XRC[2])×(HS-XRC[2]))+(RRC[2]×RRC[2]))*0.5
    ∇

      ∇TFM[⎕]∇
    ∇ TFM
[1]   HS←(+/(PSG[;IS;IN]×PSG[;IS;IN]))*0.5
[2]   PAN←¯1○(R×(1○(5×PI÷6))÷HS);GAN←¯1○(R×(1○((PI÷2)+ALD))÷HS);
      ALD←ALD×PI÷180
[3]   BRC←HS×3○(PAN,GAN)
[4]   MRC←-3○(PAN,GAN)
[5]   XRC←((-BRC×MRC)+(((R×R)+(MRC×MRC×R×R)-(BRC×BRC))*0.5))÷((1+
      (MRC×MRC)))
[6]   RRC←(MRC×XRC)+BRC;TRSO←(11,3)ρ(PSG[;IS;IN]-MTR[IN;IS;])
[7]   RDMAX←(((HS-XRC[2])×(HS-XRC[2]))+(RRC[2]×RRC[2]))*0.5
    ∇

      ∇TGEOSPH[⎕]∇
    ∇ MRC←TGEOSPH MC
[1]   MC[;2]←MC[;2]×PI÷180
[2]   MRC[;3]←(PI÷2)-(MC[;3]×PI÷180);MRC←MC
    ∇

      ∇TOPO[⎕]∇
    ∇ MRO←VT TOPO PO;OME
[1]   THR←PO[2]+(OME×VT);OME←0.004375;VX←VZ←3ρ0
[2]   XDR←(PO[1]×(1○PO[3])×2○THR)
[3]   YDR←(PO[1]×(1○PO[3])×1○THR)
[4]   ZDR←(PO[1]×(2○PO[3]))×(×VZ[3]);VZ[3]←1○PO[3]
[5]   VX[1]←(1○PO[3])×2○THR;VX[2]←(1○PO[3])×1○THR;VX[3]←2○PO[3]
[6]   VZ[1]←-(2○PO[3])×2○THR;VZ[2]←-(2○PO[3])×1○THR
[7]   VZ ANGROT VX
[8]   MRO←IMR
    ∇
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TSATCO

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      ∇TRECSPX[⎕]∇
    ∇ PSX←TRECSPX FSR;MH
[1]   PSX[;1]←(+/(FSR×FSR))*0.5;PSX←(ρFSR)ρ0
[2]   MH←((FSR[;2]×FSR[;2])+(FSR[;3]×FSR[;3]))*0.5
[3]   PSX[;2]←AREP←FSR[;2]ANGRV FSR[;3]
[4]   PSX[;3]←AREP←FSR[;1]ANGRV MH
    ∇
      ∇TSPHREC[⎕]∇
    ∇ MCC←TSPHREC MC
[1]   MCC←(ρMC)ρ0
[2]   MCC[;1]←MC[;1]×(1○MC[;3])×2○MC[;2]
[3]   MCC[;2]←MC[;1]×(1○MC[;3])×1○MC[;2]
[4]   MCC[;3]←MC[;1]×2○MC[;3]
    ∇

      ∇TVRCSP[⎕]∇
    ∇ PSX←TVRCSP FSR;MH
[1]   PSX[1]←(+/(FSR×FSR))*0.5;PSX←(ρFSR)ρ0
[2]   MH←((FSR[2]×FSR[2])+(FSR[1]×FSR[1]))*0.5
[3]   PSX[2]←AREP;FSR[1]ANGR FSR[2]
[4]   PSX[3]←AREP;FSR[3]ANGR MH
    ∇

      ∇TVSPRC[⎕]∇
    ∇ TRF←TVSPRC PO
[1]   TRF←3ρ0
[2]   TRF[1]←PO[1]×(1○PO[3])×2○PO[2]
[3]   TRF[2]←PO[1]×(1○PO[3])×1○PO[2]
[4]   TRF[3]←PO[1]×2○PO[3]
    ∇

      ∇VOPOC[⎕]∇
    ∇ MPT←VPS VOPOC MCR;VX;VZ;PO
[1]   PO←TVRCSP VPS;VX←VZ←3ρ0;MPT←(ρMCR)ρ0
[2]   MPT[;1]←MCR[;1]-VPS[1]
[3]   MPT[;2]←MCR[;2]-VPS[2]
[4]   MPT[;3]←MCR[;3]-(VPS[3]×(×VZ[3]));VZ[3]←1○PO[3]
[5]   MPT←MPT+.×(⍉MRS[IS;IN;;])
    ∇

      ∇VOPOE[⎕]∇
    ∇ MPT←VPS VOPOE MCR;VX;VZ;PO
[1]   PO←TVRCSP VPS;VX←VZ←3ρ0;MPT←(ρMCR)ρ0
[2]   MPT[;1]←MCR[;1]-VPS[1]
[3]   MPT[;2]←MCR[;2]-VPS[2]
[4]   MPT[;3]←MCR[;3]-(VPS[3]×(×VZ[3]));VZ[3]←1○PO[3]
[5]   MPT←MPT+.×(⍉MRSE[IS;IN;;])
    ∇
```

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        SATCO
        ∇CONTROL[⎕]∇
      ∇ CONTROL;PERI;APO;LONR;LATR;M;G;B;L;RSS;XS;YS;ZS;COR;I;R;
        ZI2;SCF;TMP;TOP;TDP;NLIM;NCAL;INN;IN
[1]     'STARTING TIME OF THE SIMULATION='
[2]     TO←⎕
[3]     'TIME INCREMENT='
[4]     TI←⎕
[5]     'DURATION OF SIMULATION='
[6]     TM←TO+TD←⎕
[7]     'POSITION OF THE OBSERVATION POINT'
[8]     'ALTITUDE ABOVE EARTH SURFACE=0'
[9]     ROB←R+HR←0;R←6370
[10]    'LONGITUDE=0'
[11]    THOB←LONR×PI÷180;LONR←0
[12]    'LATITUDE=0'
[13]    PHOB←(PI÷2)-(LATR×PI÷180);LATR←0
[14]    PO←ROB,THOB,PHOB
[15]    NS←1↑(ρSYSAT)
[16]    OME←0.00437;PREF[;3]←((⍳10)-1)×PI÷18;PREF←(10 3)ρ6370 0 0
[17]    NREV←10ρ0;ZI2←0;TREVS←(NS,10)ρTREV;TREV←10ρ(TO-(5×TI)+1)
[18]    REV1←REV2←REV3←REV4←REV5←REV6←REV7←REV8←REV9←REV0←0ρ0
[19]    MRF←OPO PO
[20]    POR←TVSPRC PO;MTO←MRF
[21]    NCAL←TD÷TI;NLIM←30;TDP←TD;INP←1;TOP←TO;TMP←TM;T←TO;IN←INN←1
[22]    L30:→(NCAL≥NLIM)/L20
[23]    TMP←TM;TOP←T;TDP←NCAL×TI
[24]    →L25;'TOP=';TOP;'    TMP=';TMP;POSSAT(TOP,TI,TDP)
[25]    L20:TOP←T
[26]    POSSAT(TOP,TI,TDP);TMP←TOP+(NLIM×TI);TDP←NLIM×TI
[27]    L25:T←TOP;IN←1;IS←1
[28]    L15:→(INN=1)/L17
[29]    →(IN=1)/L50
[30]    →L17
[31]    L50:
[32]    L17:→(SYSAT[IS;10]=0)/L60
[33]    →L91;STATM;TFM;ALD←SYSAT[IS;11];WSCAN←SYSAT[IS;12];PSG[;IS;
        IN]PRSM PREF
[34]    L60:STATE;TFE;ALD←SYSAT[IS;11];PSG[;IS;IN]PRSE PREF
[35]    L91:→((IS←IS+1)≤NS)/L15
[36]    L11:→((T←T+TI)≤TMP)/L15;IN←IN+1;IS←1;INN←INN+1
[37]    →(T≥TM)/L35
[38]    INP←INP+1
[39]    →L30;NCAL←NCAL-(NLIM+1);PSOZ←PSO[3;;(IN-1)];PSOY←PSO[2;;(
        IN-1)]
[40]    L35:'REV1=';REV1
[41]    'REV2=';REV2
[42]    'REV3=';REV3
[43]    'REV4=';REV4
[44]    'REV5=';REV5
```

SATCO

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      ∇CONTROL[⎕45]∇
[45]  'REV6=';REV6
[46]  'REV7=';REV7
[47]  'REV8=';REV8
[48]  'REV9=';REV9
[49]  'REV0=';REV0
[50]  'SYSAT=';SYSAT
[51]  ⍎')WSID DATACO'
[52]  ⍎')SAVE DATACO'
```

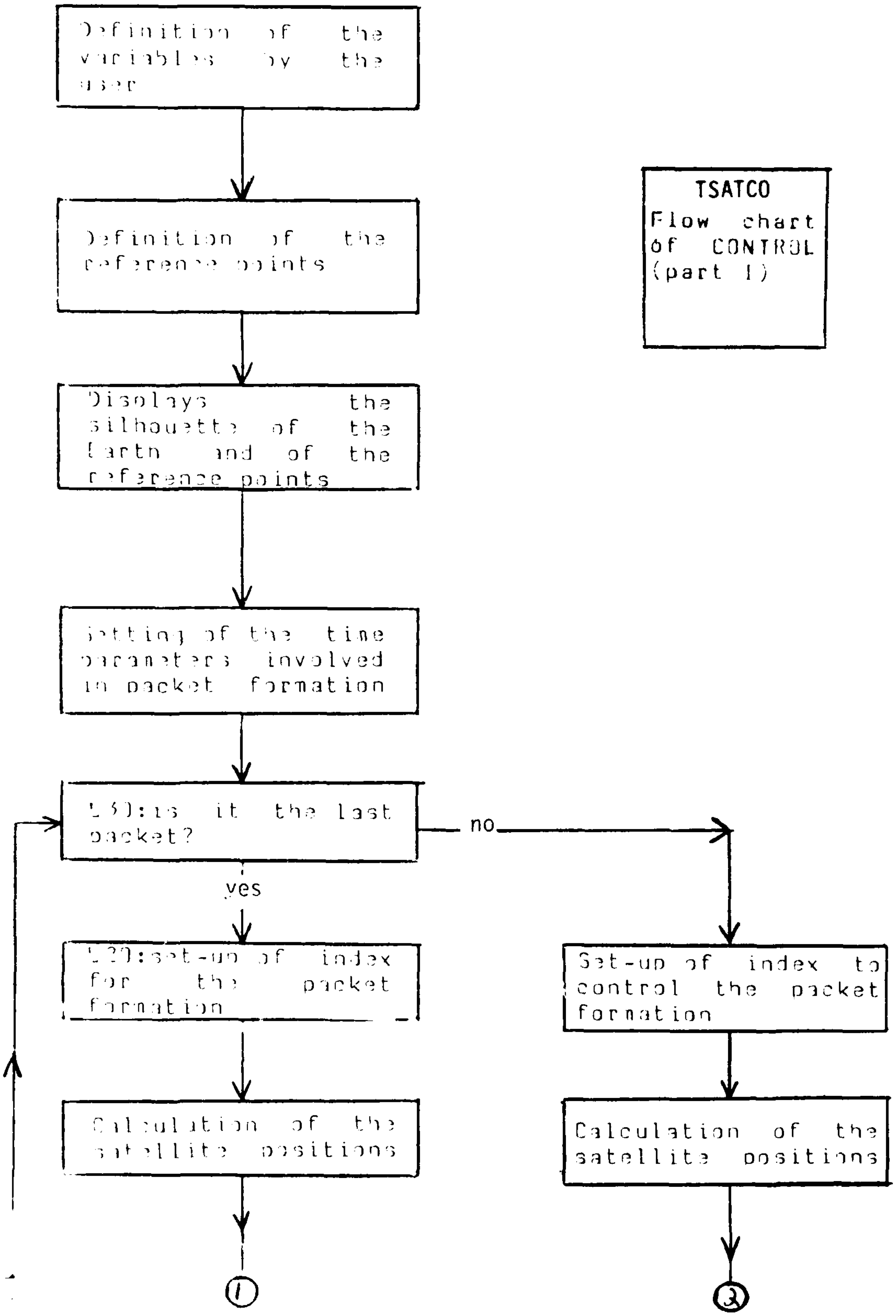
SATCO

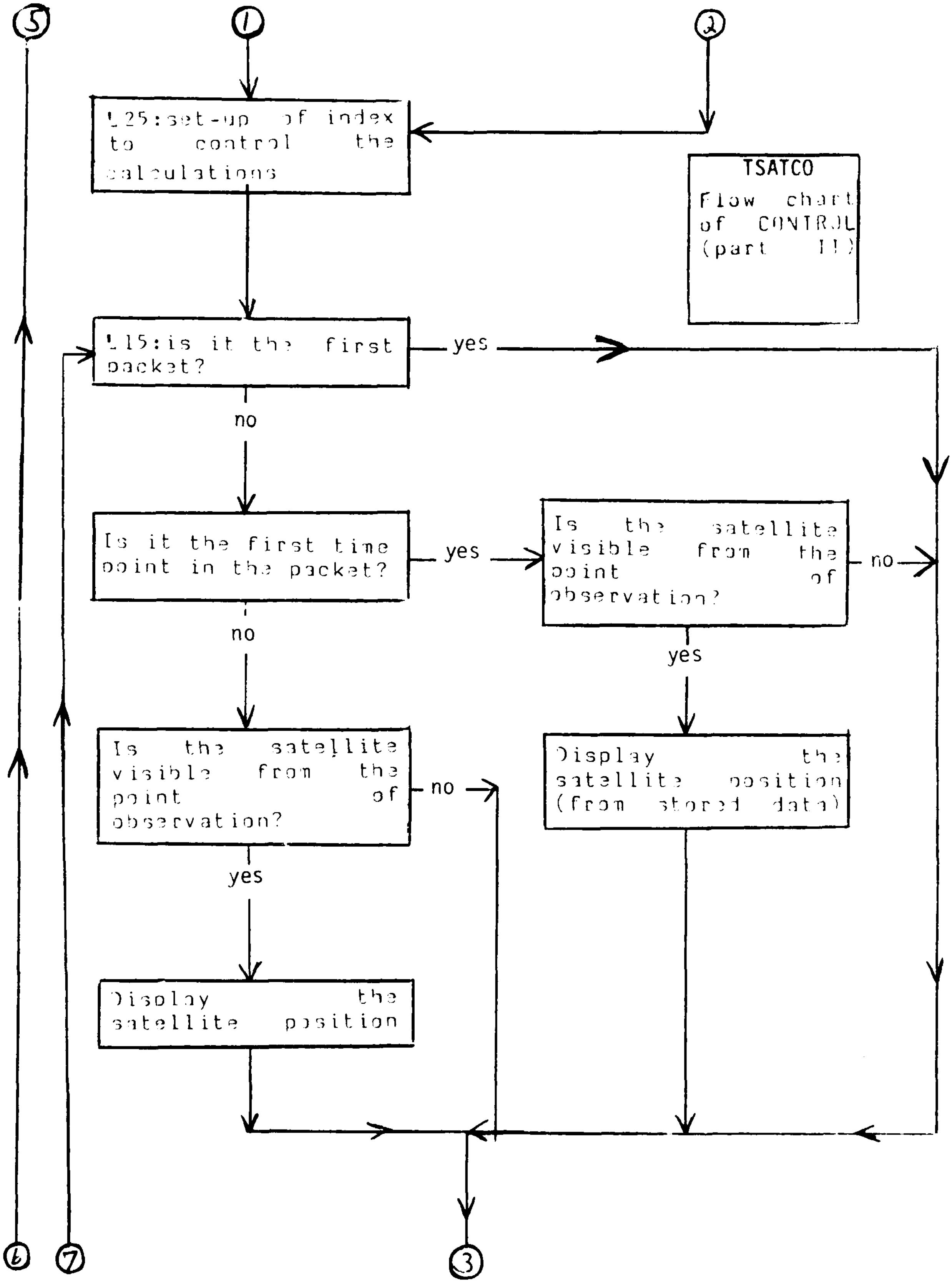
```
      ∇STATE[⎕]∇
    ∇ STATE;VPAN;VGAN;VRD;DFO;NTP;VIND;NJ;CA
[1]   VPAN←10ρPAN;VGAN←10ρGAN;VRD←10ρRDMAX
[2]   DFO←(PSX[;1]≤VRD)∧(PDS<VGAN)
[3]   NTP←+/DFO
[4]   →(NTP<1)/L5
[5]   VIND←DFO/(DFO×ι10);J←1
[6]   L1:NJ←VIND[J]
[7]   CA←'ZI2'∆FMT NJ
[8]   →(TRES≤(5×TI))/L6;TRES←T-TREVS[IS;NJ]
[9]   TREV[NJ]←T;TRE←T-TREV[NJ]
[10]  NREV[NJ]←NREV[NJ]+1;TREVS[IS;NJ]←T
[11]  DUMMY←∊'REV',CA[1;2],'←REV',CA[1;2],',TRE'
[12]  L6:→((J←J+1)≤NTP)/L1
[13]  '  '
[14]  'NTP=';NTP;'   IS=';IS;'    T=';T
[15]  'DFO=';DFO
[16]  'TREVS=';TREVS
[17]  'TREV=';TREV
[18]  'NREV=';NREV
[19]  L5:
    ∇

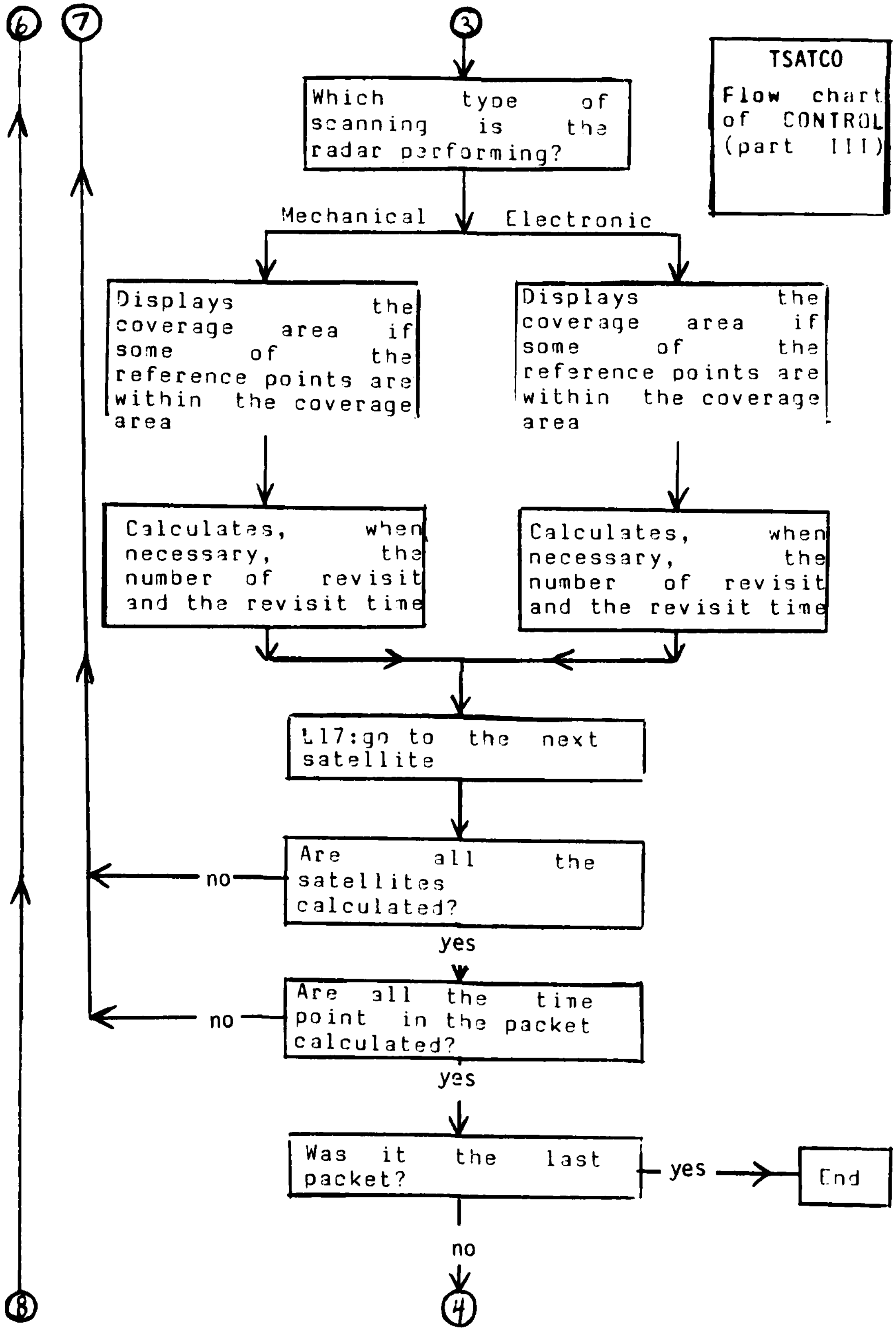

      ∇STATM[⎕]∇
    ∇ STATM;VPAN;VGAN;VRD;DFO;NTP;VIND;NJ;CA
[1]   VPAN←10ρPAN;VGAN←10ρGAN;VRD←10ρRDMAX
[2]   DFO←(PSX[;1]≤VRD)∧(PDS<VGAN)∧((((2×PI)-PSX[;2])≤(WSCAN×PI÷
      360))∨(PSX[;2]≤(WSCAN×PI÷360)))
[3]   NTP←+/DFO
[4]   →(NTP<1)/L5
[5]   VIND←DFO/(DFO×ι10);J←1
[6]   L1:NJ←VIND[J]
[7]   CA←'ZI2'∆FMT NJ
[8]   →(TRES≤(5×TI))/L6;TRES←T-TREVS[IS;NJ]
[9]   TREV[NJ]←T;TRE←T-TREV[NJ]
[10]  NREV[NJ]←NREV[NJ]+1;TREVS[IS;NJ]←T
[11]  DUMMY←∊'REV',CA[1;2],'←REV',CA[1;2],',TRE'
[12]  L6:→((J←J+1)≤NTP)/L1
[13]  '  '
[14]  'NTP=';NTP;'   IS=';IS;'    T=';T
[15]  'DFO=';DFO
[16]  'TREVS=';TREVS
[17]  'TREV=';TREV
[18]  'NREV=';NREV
[19]  L5:
    ∇
```

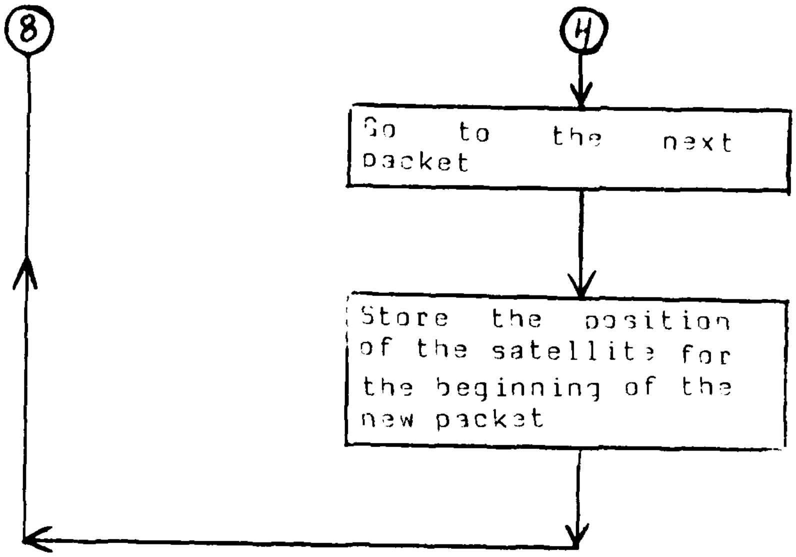
APPENDIX III

FLOW CHART OF CONTROL IN TSATCO


TSATCO
Flow chart of CONTROL (part I)
Definition of the variables by the user
Definition of the reference points
Displays the silhouette of the Earth and of the reference points
Setting of the time parameters involved in packet formation
L50: is it the last packet?
no
yes
L20: set-up of index for the packet formation
Calculation of the satellite positions
Set-up of index to control the packet formation
Calculation of the satellite positions
1
2


5
1
2
L25:set-up of index to control the calculations
TSATCO
Flow chart of CONTROL (part II)
L15:is it the first packet?
yes
no
Is it the first time point in the packet?
yes
Is the satellite visible from the point of observation?
no
no
yes
Is the satellite visible from the point of observation?
no
yes
Display the satellite position (from stored data)
Display the satellite position
6
7
3


6
7
3
TSATCO
Flow chart of CONTROL (part III)
Which type of scanning is the radar performing?
Mechanical
Electronic
Displays the coverage area if some of the reference points are within the coverage area
Displays the coverage area if some of the reference points are within the coverage area
Calculates, when necessary, the number of revisit and the revisit time
Calculates, when necessary, the number of revisit and the revisit time
L17:go to the next satellite
Are all the satellites calculated?
no
yes
Are all the time point in the packet calculated?
no
yes
Was it the last packet?
yes
End
no
8
4

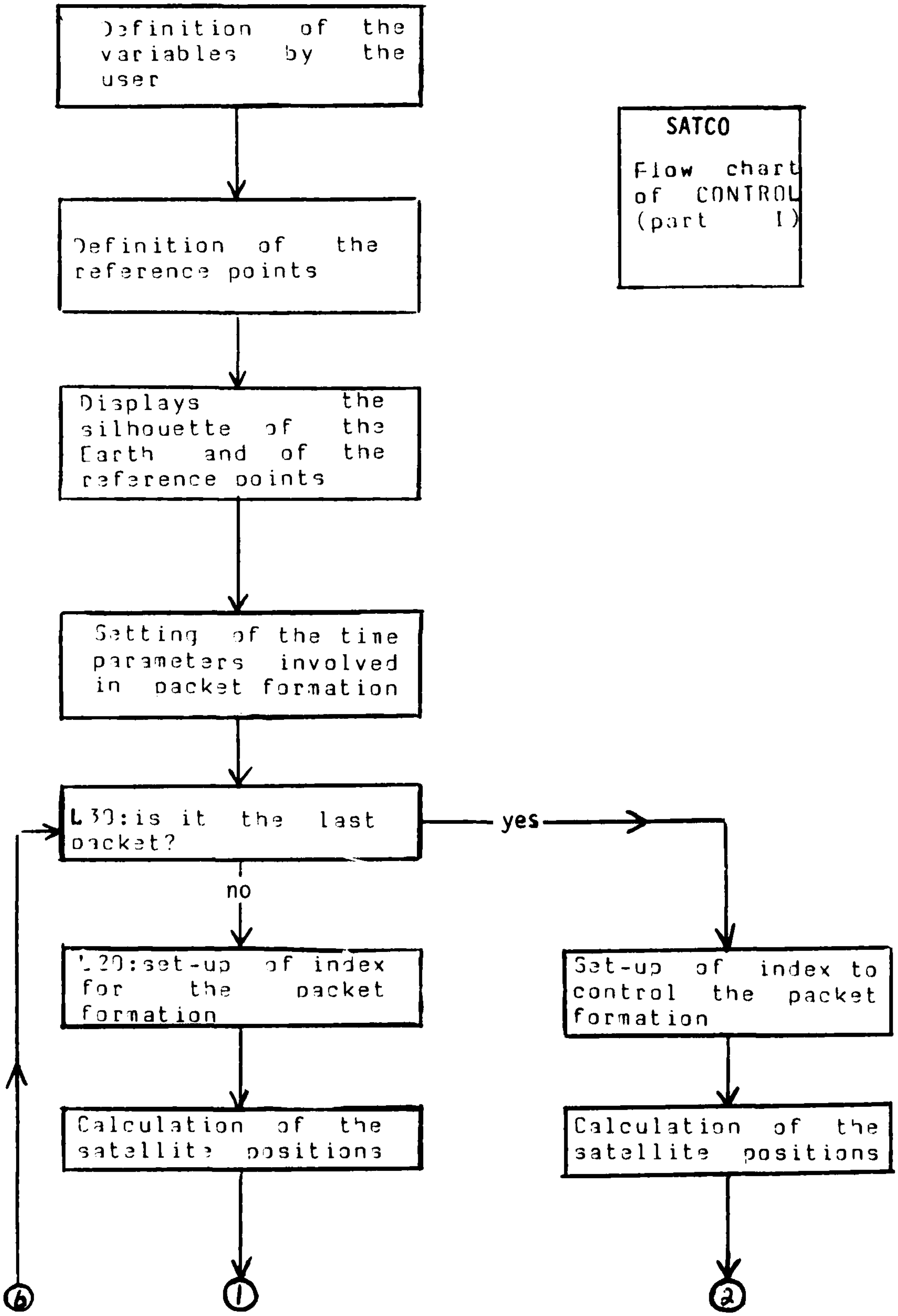


TSATCO

Flow chart of CONTROL (part IV)

APPENDIX IV

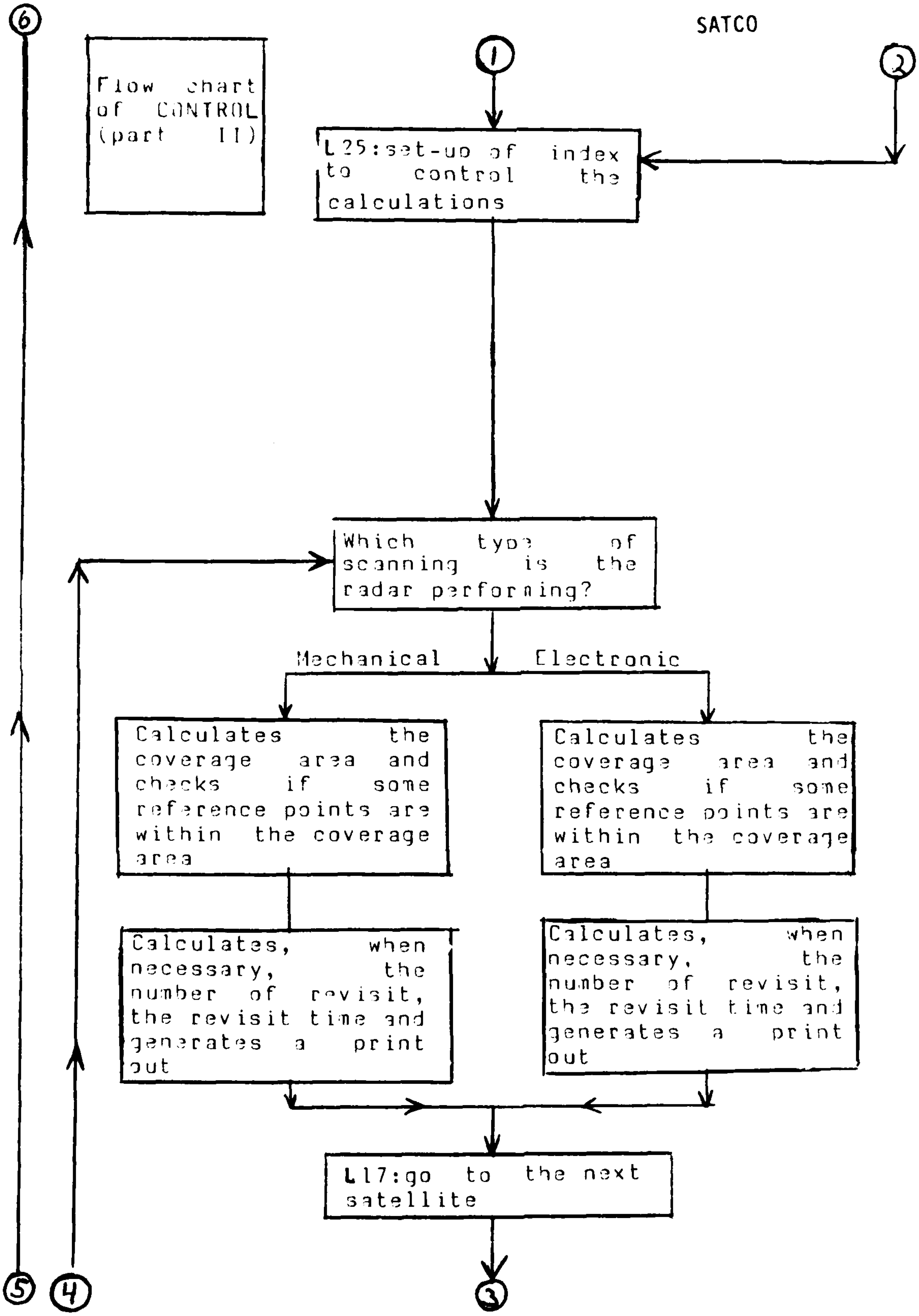
FLOW CHART OF CONTROL IN SATCO



SATCO

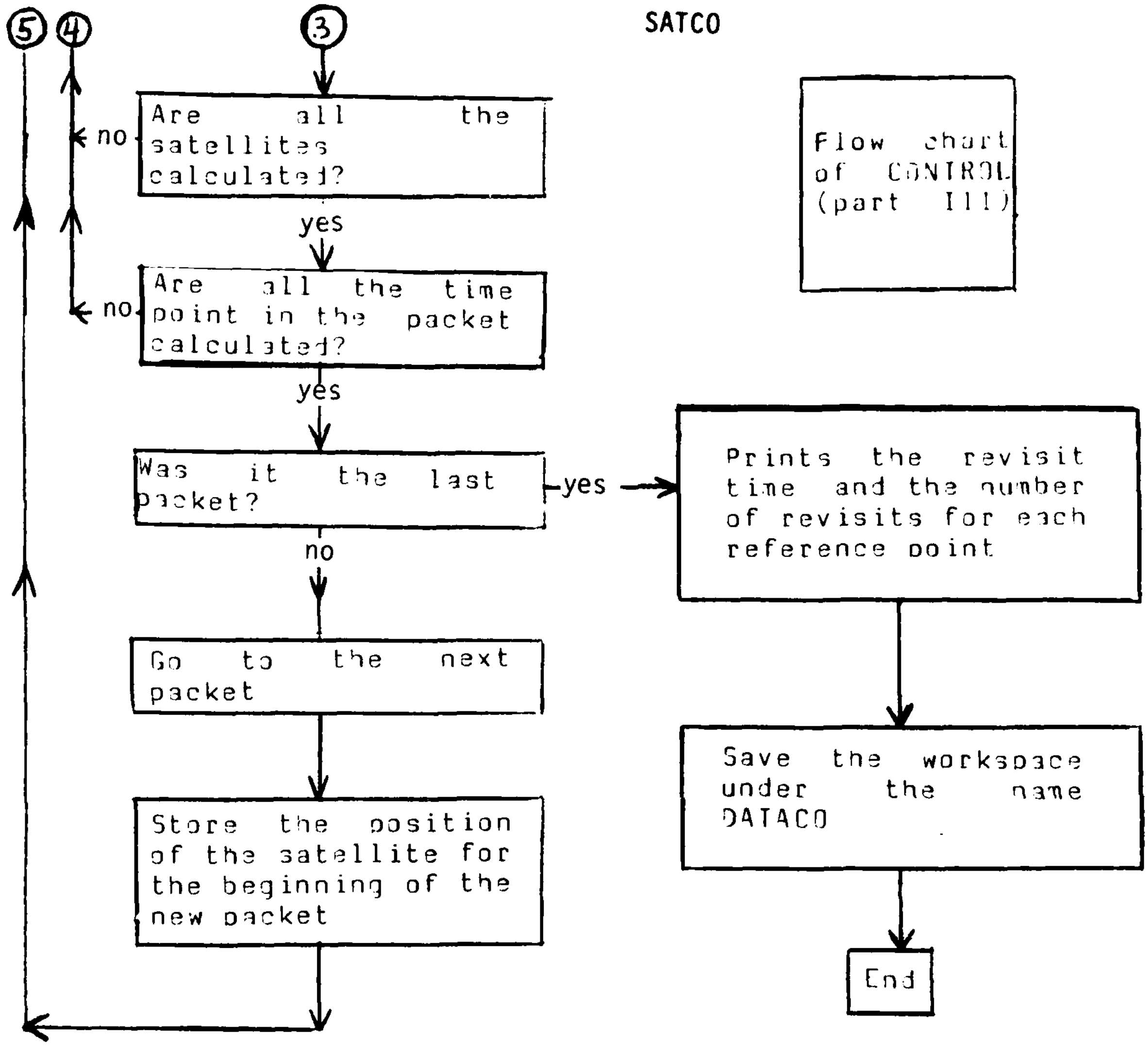
Flow chart of CONTROL (part I)

SATCO



Flow chart of CONTROL (part II)

SATCO



3
4
5
Are all the satellites calculated?
no
yes
Are all the time point in the packet calculated?
no
yes
Was it the last packet?
yes
no
Go to the next packet
Store the position of the satellite for the beginning of the new packet
Flow chart of CONTROL (part III)
Prints the revisit time and the number of revisits for each reference point
Save the workspace under the name DATACO
End

TSATCO

```
      ∇ANGR[⎕]∇
    ∇ AX ANGR AY;VCA
[1]   →(AX≠0)/L1
[2]   →L2;AREP←((PI÷2)×(AY>0))+(3×PI÷2)×(AY<0)
[3]   L1:VCA←((AY≥0)∧(AX≥0)),((AY≥0)∧(AX<0)),((AY<0)∧(AX<0)),((
      AY<0)∧(AX>0))
[4]   AREP←AREP,(PI-AREP),(PI+AREP),((2×PI)-AREP);AREP←¯3○|AY÷AX
[5]   AREP←+/VCA×AREP
[6]   L2:
    ∇
      ∇ANGRV[⎕]∇
    ∇ AREP←AX ANGRV AY;VCA;LV;V;ARE
[1]   AREP←(⍴AX)⍴0;LV←⍴AX;V←1;→((⍴AX)≠(⍴AY))/L10
[2]   L11:→(AX[V]≠0)/L1
[3]   →L2;AREP[V]←((PI÷2)×(AY[V]>0))+(3×PI÷2)×(AY[V]<0)
[4]   L1:VCA←((AY[V]≥0)∧(AX[V]≥0)),((AY[V]≥0)∧(AX[V]<0)),((AY[V]<
      0)∧(AX[V]<0)),((AY[V]<0)∧(AX[V]>0))
[5]   ARE←ARE,(PI-ARE),(PI+ARE),((2×PI)-ARE);ARE←¯3○|AY[V]÷AX[V]
[6]   AREP[V]←+/VCA×ARE
[7]   L2:→L12;→((V←V+1)≤LV)/L11
[8]   L10:'ERROR FROM ANGRV THE ARGUMENT DO NOT HAVE THE PROPER L
      ENGTH'
[9]   L12:
    ∇
      ∇BROWNS[⎕]∇
    ∇ F←BROWNS MT;NU;G;M;NB;MNB;MB
[1]   NU←G×M;G←2.4E¯16;M←5.97E24
[2]   NB←(NU÷A×A×A)*0.5
[3]   MNB←⍉(NT,NS)⍴NB
[4]   MTP←MT-0.01;MTS←MT+0.01;MT←MT+(⍉(NT,NS)⍴SYSAT[;9])
[5]   ME←⍉(NT,NS)⍴E;MB←MNB×MT;MBP←MTP×MNB;MBS←MTS×MNB
[6]   CB←(1○MB)÷((1+(ME×ME)-(2×ME×2○MB))*0.5)
[7]   CBP←(1○MBP)÷((1+(ME×ME)-(2×ME×2○MBP))*0.5)
[8]   CBS←(1○MBS)÷((1+(ME×ME)-(2×ME×2○MBS))*0.5)
[9]   VC1←((CBP<CB)∧(CBS≥CB)∧(CB≥0))×1
[10]  VC2←(((CBP≥CB)∧(CBS<CB)∧(CB≥0))×2)+(((CB≤1)∧(CB>1))×2)
[11]  VC3←((CBP>CB)∧(CBS≤CB)∧(CB<0))×3
[12]  VC4←(((CBP≤CB)∧(CBS>CB)∧(CB<0))×4)+(((CB≥¯1)∧(CB<¯1))×4)
[13]  VC←VC1+VC2+VC3+VC4
[14]  CB←¯1○(|CB)
[15]  CB←(CB×(VC=1))+((PI-CB)×(VC=2))+((PI+CB)×(VC=3))+(((2×PI)-
      CB)×(VC=4))
[16]  F←¯1○|AR;AR←((1○CB)×((1-(ME×ME))*0.5))÷VDE;VC←((2○CB)-ME)÷
      VDE;VDE←(1-(ME×2○CB))
[17]  F←(F×((AR≥0)∧(VC≥0)))+((PI-F)×((AR≥0)∧(VC<0)))+((PI+F)×((
      AR<0)∧(VC<0)))+(((2×PI)-F)×((AR<0)∧(VC>0)))
    ∇
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